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Apparatus and Procedure for Determining Oil Droplet Size Distribution

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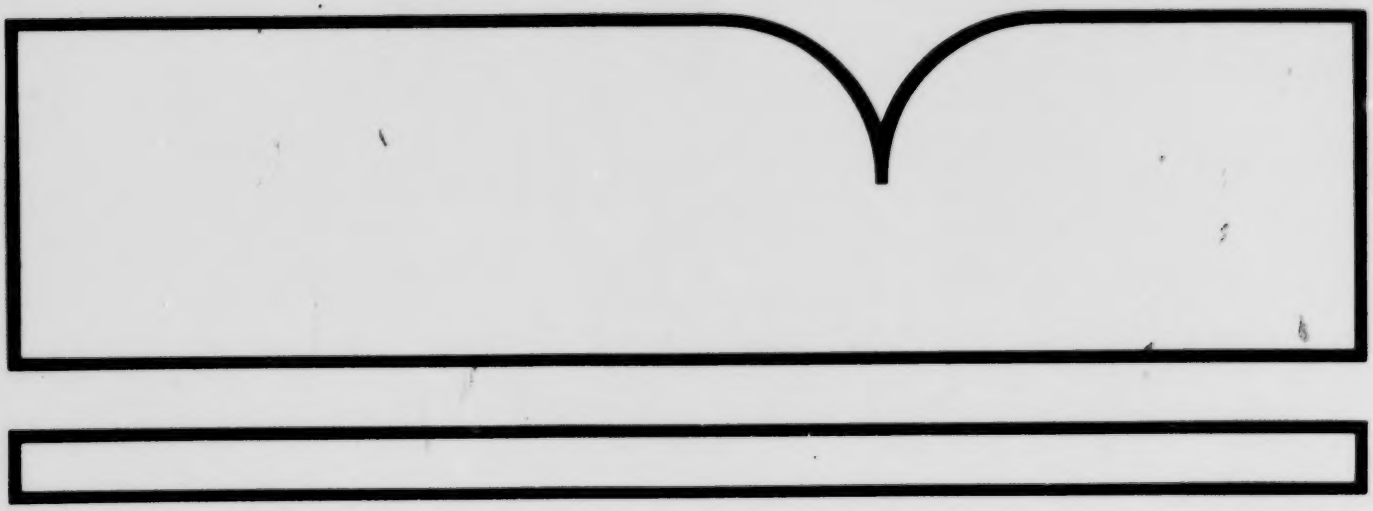

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APPARATUS AND PROCEDURE FOR DETERMINING OIL DROPLET SIZE DISTRIBUTION

by

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16. ABSTRACT

This program was initiated to develop a method and apparatus for determining the oil drop size distribution in flowing oily brine during brine cleanup treatment. An automated photomicrographic apparatus for taking time-lapse photographs of oily brine that was briefly at rest is described. This apparatus meets all N.E.C. Class 1, Division, 1, Group D requirements for operation where explosive concentrations of hydrocarbons are known to exist. The system demonstrates its ability to determine the size and number distribution of 2- to 100-micrometer spherical entities, and it establishes their density as well. Thus the technique can differentiate between oil drops, oil-covered gas bubbles, and oil-covered sand or other solids. The report presents both the techniques for reducing the photomicrographs to size and number data, and the Fortran programs involved. Although developed for oil particles in brine on offshore production platforms (where the device has obtained some 20,000 photos for the parent study), the apparatus and technique are equally well suited for characterizing the distribution of any immiscible minor component in a semi-transparent fluid matrix.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

A salt brine normally accompanies oil as it emerges from the earth. Significant amounts of oil remain dispersed in the brine after primary separation from the produced oil. In an effort to minimize hydrocarbon release to the environment, oil producers employ several types of final brine treatment systems. They all ultimately depend on oil drops rising through the brine to a collection area. Drop diameter is a major factor in establishing the speed of separation, since rise rate is proportional to the square of the drop diameters. This study aims to develop a better understanding of the drop size distribution in oily brine streams. This knowledge could improve the application of present equipment and aid in development of even better techniques.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

This program was initiated to develop a method and apparatus for determining the oil drop size distribution in flowing oily brine during brine cleanup treatment.

An automated photomicrographic apparatus for taking time-lapse photographs of oily brine that was briefly at rest is described. This apparatus meets all N.E.C. Class 1, Division 1, Group D requirements for operation where explosive concentrations of hydrocarbons are known to exist. The system demonstrates its ability to determine the size and number distribution of 2- to 100-micrometer spherical entities, and it establishes their density as well. Thus the technique can differentiate between oil drops, oil-covered gas bubbles, and oil-covered sand or other solids.

The report presents both the techniques for reducing the photomicrographs to size and number data, and the Fortran programs involved.

Although developed for oil particles in brine on offshore production platforms (where the device has obtained some 20,000 photos for the parent study), the apparatus and technique are equally well suited for characterizing the distribution of any immiscible minor component in a semi-transparent fluid matrix.

This report was submitted in partial fulfillment of Contract 68-03-2648 by Rockwell International under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period from June 1978 to November 1980, and work was completed in June 1981.

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ENGLISH-METRIC CONVERSION

1 inch = 25.4 mm = 2.54 cm

1 foot = 0.3048 meter

1 pound per square inch = 6.895 kpa

1 inch water head = .249 kpa

1 cm water head = .098 kpa

1 gallon per minute = 3.785×10^{-3} cubic meters per minute

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SECTION 1

INTRODUCTION

Production of oil-brine mixtures, pumping, and pipeline flow all result in a dispersal of the oil in the brine. In an effort to reduce the hydrocarbon discharge to the environment, the Offshore Oil Producers Association and the Municipal Environmental Research Laboratory cooperated in a production platform study. Characterization of the oily brine at several points in the oil removal treatment process, study of the effectiveness of several treatment techniques, and comparison of analytical methods were among the goals of the study.

Oil-brine separation methods ultimately depend on the oil drops rising through the brine to a collection area. This rise rate is proportional to the density difference between the oil drops and the brine, but is proportional to the square of the diameter of the drop. Thus a major governing factor in the success of brine treatment for oil removal is the size range and distribution of oil drops.

Knowledge of the oil drop size distribution at several places in the produced water treatment system would aid in the application of present separation techniques and in the development of future systems. Therefore, a part of the platform study was directed toward measurement of the drop size distribution in the primary oil-water separator feed, the final treatment unit feed, and the produced water outfall. Emphasis was on offshore production, but the development is equally applicable to onshore production.

A number of nonspecific techniques exist for characterizing particle size distribution. All are based on measurement of the particle's effect in the interruption of some flow of energy such as light, radiation, or electricity. These methods are nonspecific and report gas bubbles and solid particles as oil drops. They are inadequate because the produced brine contains non-oil material, e.g., sand, shells from microorganisms, gas bubbles from dissolved gas, and gas bubbles intentionally introduced to implement the oil removal flotation process. Therefore any of the nonspecific techniques would be expected to give erroneously high oil contents and misleading oil drop size distributions. Additionally, to obtain meaningful size measurement, only one particle may be in the measuring path at a time. This is typically achieved by severely limiting the path length. While this is quite acceptable when dealing with solids, the high shear introduced by passing the sample through the small orifice would be expected to alter the oil drop size distribution and render the data meaningless. For these reasons, the existing techniques were considered unsuitable for the determination of oil drop size dispersions.

A micrographic technique may be implemented that does not introduce significant shear forces on the oil drop population. The technique was developed into an automated photomicrographic system (PMS) that met the requirements of the National Electrical Code Class 1, Division 1, Group D. This permitted its use on production platforms where explosive concentrations of hydrocarbons were known to exist.

Conventional micrography involves capturing a sample, placing it on a slide, perhaps in a shallow well, and counting or measuring the entities of interest. This typically is done at leisure since the sample is stable over a relatively long time. Such is not the case when studying oil drop dispersion. As soon as the turbulent mixing motion dissipates, the sample starts to stratify due to the density disparity between the oil drops and the brine matrix. This dispersion alteration proceeds at such a rapid rate that the sample would be useless within 20 seconds. Accordingly, the PMS was developed along the lines of a flowthrough system.

A flowthrough microscope cell was constructed and the microscope illumination changed from the conventional continuous light source to electronic flash illumination. The flash gun used, a Model 611 Sun-Gun, had a reported flash duration of 20 microseconds at the 1/128 power setting. However, when the sample was flowing fast enough to maintain turbulent mixing, the linear drop movement was too rapid to give sharp photographs. Accordingly, an interrupted flow system was designed where the flow was blocked by a downstream valve and the photograph taken 0.1 second later. This system resulted in clear, sharp photographs of spherical entities and microscopic shells of fossilized organisms.

The spherical entities were initially thought to be nothing but oil drops. However, the oil content of a Wemco (final oil removal unit) outlet sample, calculated from measured drop diameters and count, was found to be much larger than that determined by conventional solvent extraction techniques. The rationale was offered that not all the photographed, measured, and counted spherical entities were oil. This seemed logical, since the function of the Wemco treating unit was to mix gas bubbles into the water in an effort to "parachute" the oil drops to a surface skimmer. These bubbles could well be covered with a film of oil and be photographically similar to actual oil drops. This problem led to the development of a technique to apply time-lapse microphotography to the determination of number, size, and, most importantly, the density of the spherical entities.

In the normal, vertical orientation of the microscope viewing axis, Figure 1, where a series of simulated time-lapse photographs are combined, the oil drops rise toward the top of the cell and thus move in and out of focus. However, if the axis of the microscope were turned horizontal, Figure 2, the drop would remain in focus and only change position in the field of view as it rises. Drop movement would therefore be across the field of view of the microscope. Thus the series of combined photographs show the drop image in several positions as it moves. The vertical movement of the oil drops and air bubbles could now be measured by comparison of their positions in two photographs taken a known time interval apart. If the rise rates and diameters were known, the densities of the spherical entities could be determined by application of Stokes Law. It required only slight modification of the original

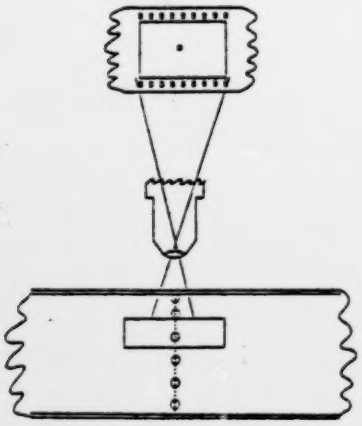

Figure 1. Drop movement with normal vertical microscope axis orientation.

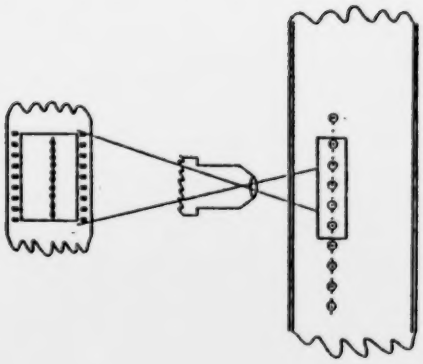

Figure 2. Drop movement with nontypical horizontal microscope axis orientation.

system to permit its operation "on its back" with the viewing axis horizontal.

The final system is illustrated in Figure 3, which shows a line diagram of the PMS as viewed from above while in its operating position. The horizontal orientation of the microscope viewing axis and its relation to the flowthrough cell and film plane are shown. Both the camera focusing magnifier and the microscope oculars are designed to be used from the side of the PMS when it is in the operating position. The camera was positioned with the long, 34-mm axis of the film vertical. An electronic control circuitry was developed to sequence the sample flow and the three time-lapse photographs.

An apparatus embodying this technique has been constructed and used both in the laboratory and on offshore oil production platforms. The system is automated, self-contained, battery-operated, and enclosed in an inert gas pressurized case. The system as designed is applicable to liquids in turbulent flow within pipelines at pressures less than 170 kPa (10 psig). It could easily be modified to accept higher pressure samples. Minor changes in the positioning of the microscope and changes in the photograph timing could adapt the PMS to study other liquid-borne particulate systems.

Figures 4 and 5 are side view photographs of the final apparatus, and Figure 6 is a detail view of the lower section.

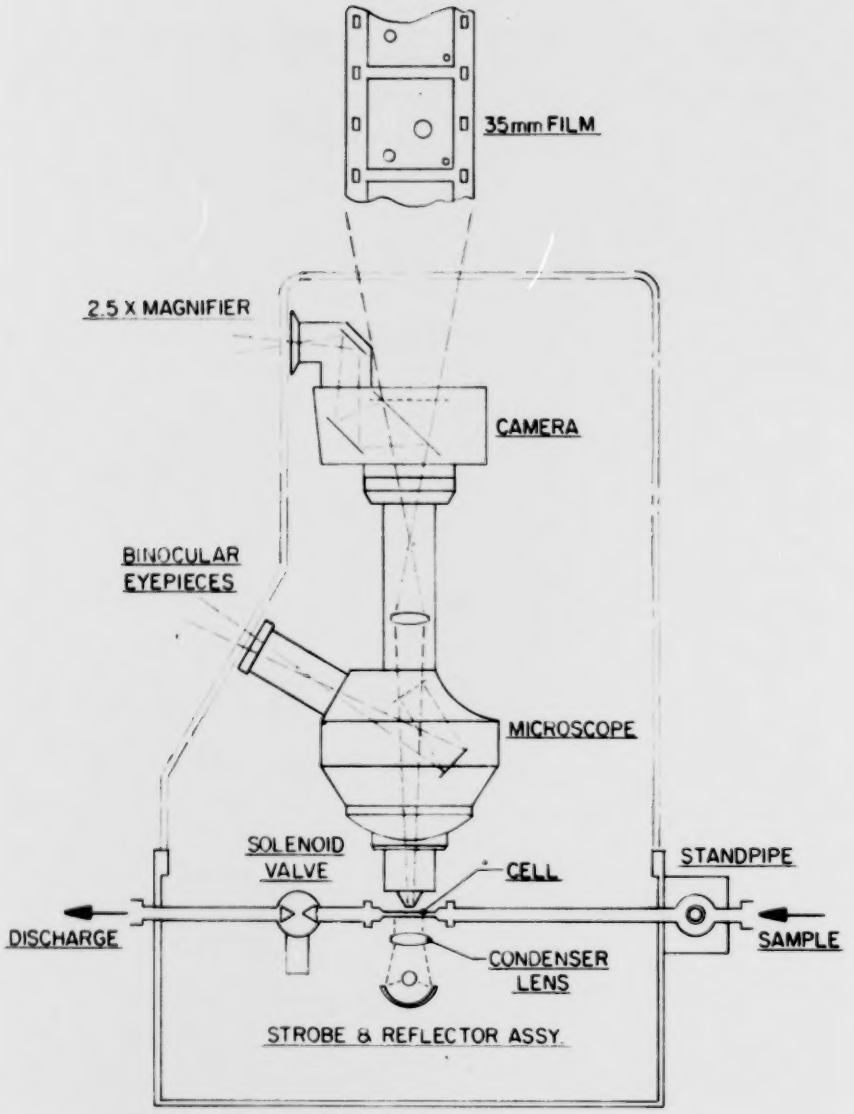

Figure 3. Top diagrammatic view of photomicrographic system.

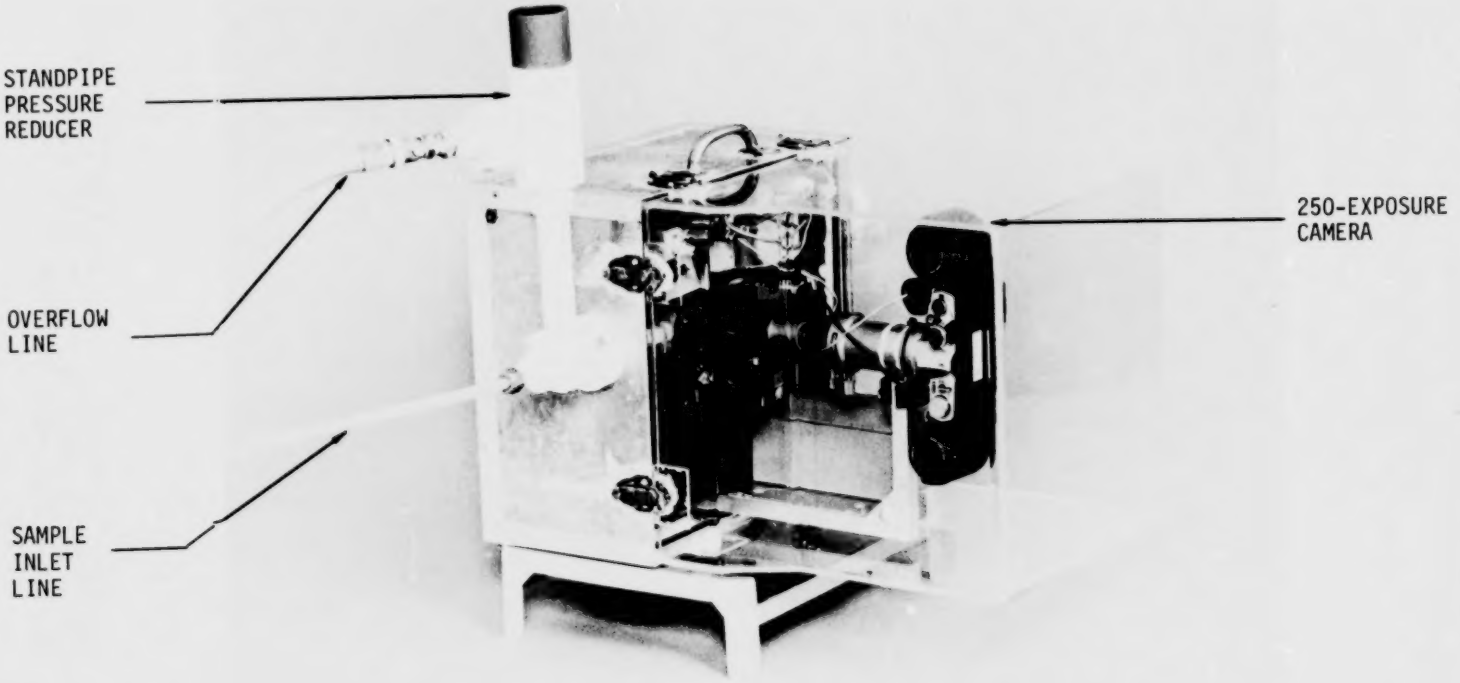

Figure 4. Left side view of the final apparatus

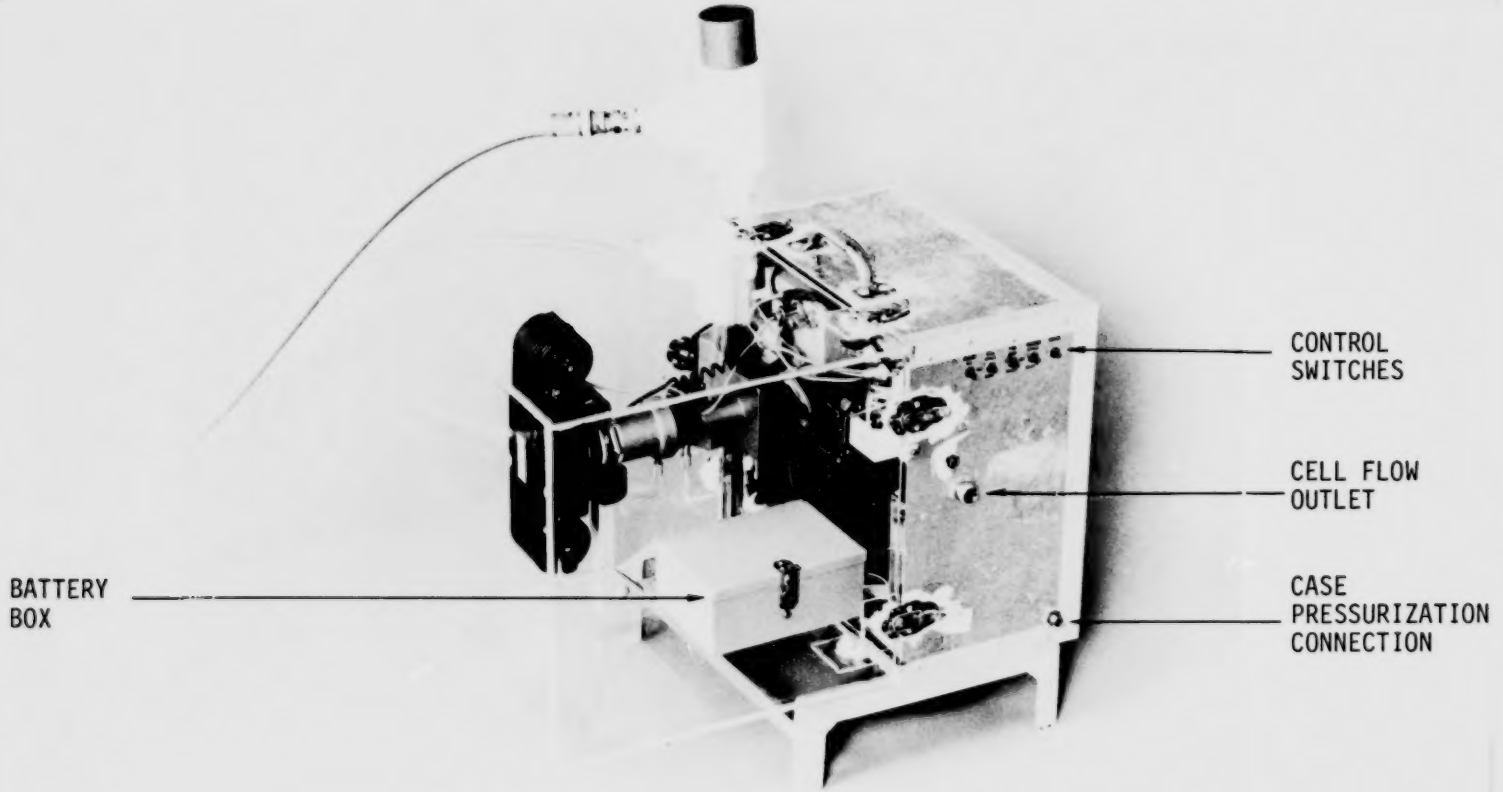

Figure 5. Right side view of the final apparatus.

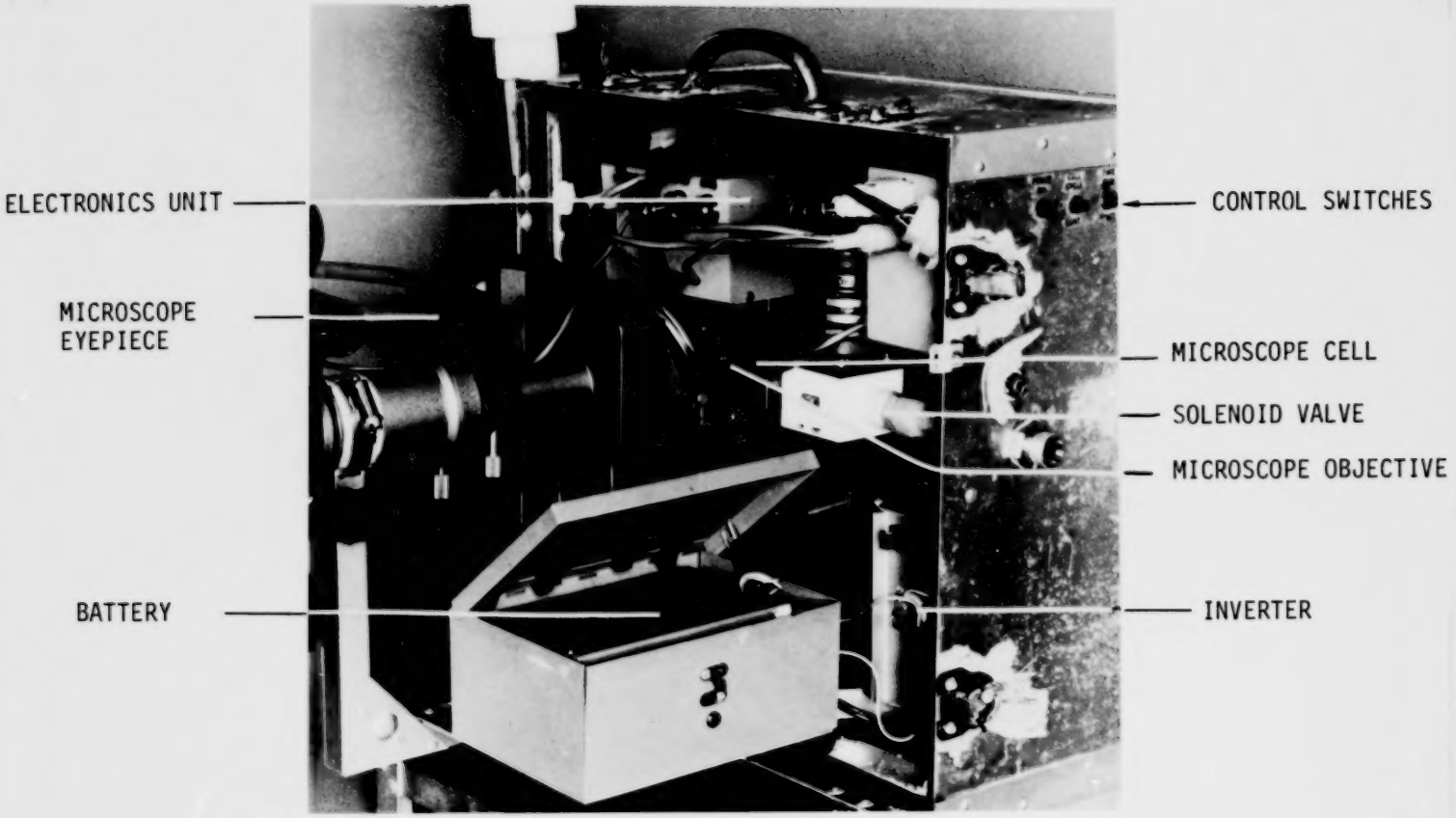

Figure 6. Detail right side view of lower section.

SECTION 2

CONCLUSIONS

Apparatus for determining the number, diameter, and density of particles 2 to 200 micrometers in diameter under flowing conditions has been developed. The battery-operated device is 63 cm long, 55 cm high, and 55 cm wide, and weighs 16 kg. It is designed to be safely operated in explosive atmospheres.

The apparatus described in this report was successfully operated on offshore oil production platforms. Over the period of the study, a nominal 20,000 color photographs were taken of uncompromised samples from flowing oily brine systems. The data were reduced to numerical size and number oil drop distributions and form part of the data reported in the complete study, "Oil Content in Produced Brine on Ten Louisiana Production Platforms," to be available from the NTIS.

SECTION 3

RECOMMENDATIONS

The system should be modified to use color video tape recording instead of photography. As a no-cost adjunct to the program, one of the authors, Fred Howard of Esoteric Systems Corp., demonstrated the feasibility of applying color video photography and recording to the technique. This method of data acquisition proved to be much better than the photographic methods described in this report. If color video recording is used, time-lapse images may be obtained every 33 milliseconds. The video images may be rapidly reduced by application of existing pattern recognition programs. By comparison, the data reduction and photograph processing steps are time-consuming and costly (about 60¢ per time-lapse triad and 3 minutes to reduce the data from the photographs). These costs and manhour requirements severely limit the size of the data base. Additionally, the video system seems to present a unique opportunity to study oil drop coalescence. The use of the video system is not limited to automated data reduction since "freeze-frame" systems are readily available in the home market.

Although the system and procedure was developed for the specific purpose of oil drop distribution study, the same apparatus is equally applicable to other sparse dispersion in fluid media. For example, if the entities to be studied are heavier than the media, the viewing cell would be located near the bottom of the microscope cell. The present electronics provide for either time-lapse or single-shot photography. The electronic timing matrix is adjustable over a wide range and has several unused control ports that may be used to control additional actions in another system. Thus, in addition to fulfilling its original purpose, this photomicrographic system has wide potential in the hands of an innovative researcher.

SECTION 4

THEORETICAL DISCUSSION

Successful implementation of the design depends upon maintenance of sample integrity through the steps of pipeline sampling, sample transport, pressure reduction and photography. Each of these phases of the investigation has the potential of altering the oil drop size and rendering the data meaningless. The following discussion will show that the sample remains unaltered throughout its journey to the microscope cell and that the photomicrographs do indeed capture the oil drops in a representative sample of the pipeline flow.

SAMPLE FLOW OUT OF THE PIPELINE

The first requirement for valid data acquisition is that the liquid in the pipeline to be sampled be uniformly dispersed. Reynolds numbers in excess of 3000 indicate the turbulent flow region where such dispersion occurs. The calculation of Reynolds number requires knowledge of the viscosity of the flowing liquid. Experimental-based knowledge of the brine viscosity under field conditions was not available. The techniques described in Appendix A were used to estimate this parameter. Data for fresh water, sea water, and the produced brines on three of the platforms studied are presented in Table 1.

Figures 7 and 8 show flowrates required to maintain turbulent flow for typical brine and sea water as a function of inside pipe diameter. Dimensions are also given in common engineering units for greater utility.

The sample port configuration in a field pipeline is seldom under the investigator's control. Field sample points in one study ranged from a very

TABLE 1. PHYSICAL PARAMETERS OF SEVERAL MATRIX LIQUIDS

Fluid/Platform	Fresh Water	Sea Water	Offshore Platform Number SP65B	WD45C	ST177
Density, gm/ml	.9901	1.017	1.086	1.072	1.151
Temperature, ^{o}C	40	40	38.6	40	36.1
Estimated Viscosity, Centistokes	0.63	0.71	0.815	0.765	1.021

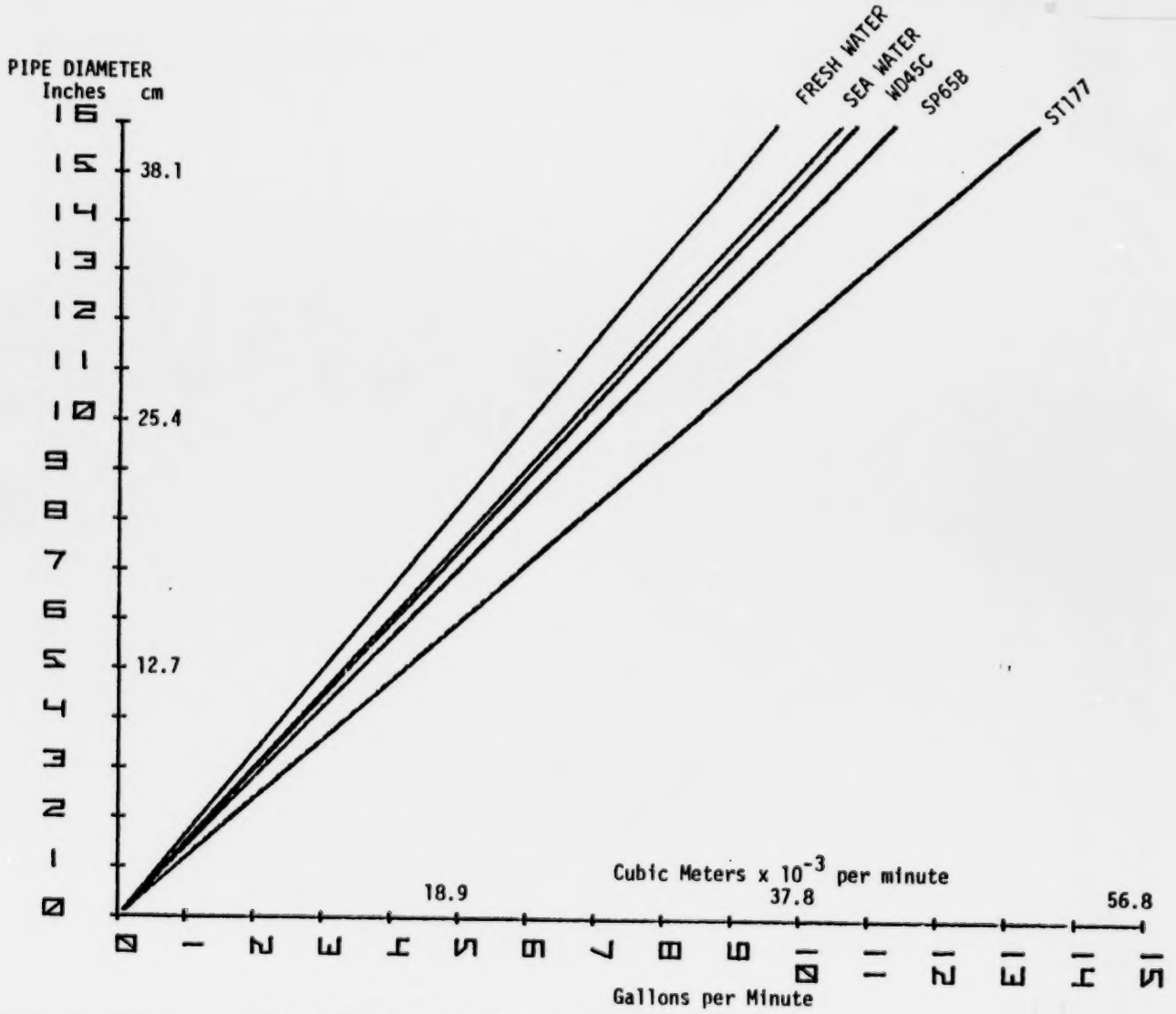

Figure 7. Flow for Reynolds Number of 3000.

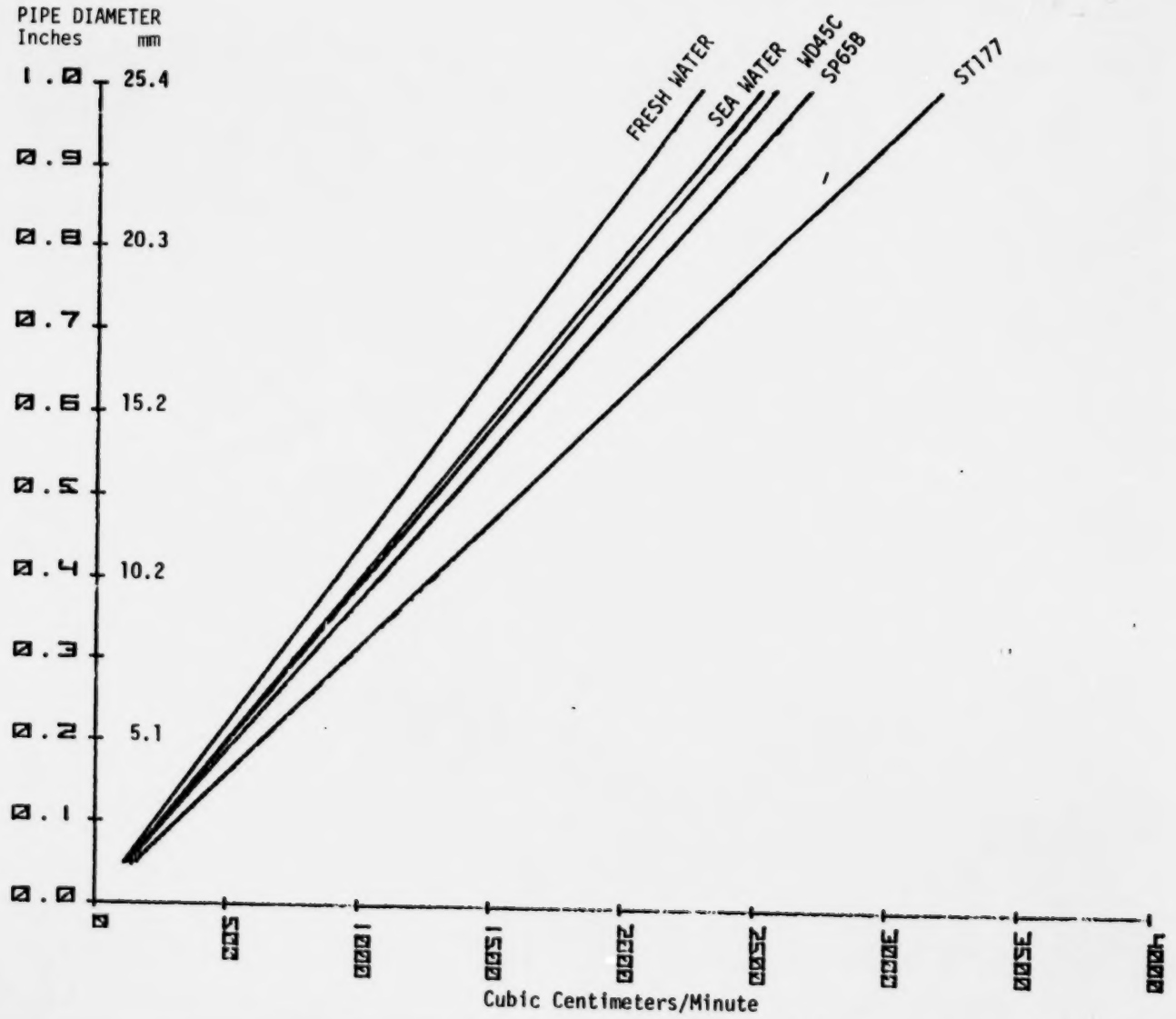

Figure 8. Flow for Reynolds Number of 3000.

undesirable 6.35-mm (1/4-in) needle valve in the side of a 20.3-cm (8-in) pipe to a 19-mm (3/4-in) gate valve that allowed insertion of a sampling tube. Ideally, the sampling would be isokinetic, but this luxury is seldom available. It remains to attempt to evaluate the effect of the several available sampling techniques upon the oil size dispersion in the extracted sample.

The petroleum industry's interest in transporting and sampling dilute suspensions has led to several reported studies of the subject (1-3). The 1964 work of Rushton and Hillested contained an experiment where kerosene was dispersed in water and weak brine. The results cannot be considered directly applicable because the kerosene was present in the 1% to 10% range and had a density of 0.79 compared with the 0.84 to 0.89 densities of the oil studied. The Summary of Recommendations is given below:

"Summary of Recommendations

Two-phase flow can be sampled either in a horizontal or vertical pipe with good precision. For either horizontal or vertical pipes, a probe consisting of a pitot type appears to be the most accurate, but either a circular port sampler or a 45-degree cut sample tube can be used with about the same accuracy. The circular port sampler is preferred because it is easier to insert and is less subject to damage than the pitot type, and its use resulted in data that scatter less from average values than the data from the 45-degree sampler.

For sampling in a horizontal pipe:

1. The sampling probe should be located at least 20 pipe diameter (PD) and preferably 40 PD or more downstream from any elbow, valve, or other pipe fitting.

2. The probe opening should be placed at the center of the cross-section of the pipe and pointed precisely upstream.

3. The sample should be withdrawn at a rate such that the velocity of flow (feet per second) through the probe opening is equal to the centerline velocity (isokinetic). However, for practical purposes the sample can be withdrawn at 1.2 times the average velocity of flow.

4. The average concentration in the pipe is calculated by dividing the composition of the sample by a value V.

5. Openings flush with the pipe wall, elbow wall, or pump wall do not yield reproducible results for systems that are difficult to suspend. Such systems are those whose settling ratios, S, are above 1.0. For systems whose settling ratios, S, are below 1.0, and whose concentration gradient, -m, is less than 0.1, a side-wall tap will give satisfactory results.

6. Use of a circular port probe under the conditions described in the preceding paragraphs (see Items 1 through 4) will result in samples

whose reproducible average will be within 8% of stream composition for a wide variety of systems, and within 2% for a large majority of suspensions likely to be encountered in petroleum operations.

For sampling in a vertical pipe, upward flow, pipe precisely vertical:

1. The sample probe opening must be pointed downward, precisely vertical, and at least 3 PD above any elbow or fitting.

2. The probe opening should be placed at the center of the pipe cross-section.

3. The sample should be withdrawn at a rate such that the velocity of flow through the probe opening is equal to the centerline velocity of the flowing stream. It is satisfactory to calculate centerline velocity as 1.2 times average velocity of flow.

4. Use of a circular probe under the conditions described in Items 1 through 3 will result in samples that will equal the average composition within ±0.05 absolute percent by volume. It is not necessary to use an adjustment factor as is the case for the condition described in Item 4 for the horizontal pipe."

The withdrawal probe, used as recommended, will give a sample that can be accurately related to the average composition that flows through the pipe, and deviations in position and withdrawal velocity will result in a change of sample composition. Such changes are primarily the result of the settling rate of the dispersed phase, the rate of withdrawal of the sample, and the rate of flow in the pipe.

Note that isokinetic sampling (where the linear velocity through the opening of the sampling probe is equal to the linear velocity in the pipe in front of the opening) is recommended for sampling in both vertical and horizontal pipes. Nonisokinetic sampling can be done with equally accurate results, but a knowledge of concentration gradient (which is a function of settling velocity, pipe size, and rate of flow) is necessary so that the ratio between sample composition and average pipeline composition can be determined. To this end, a method has been found and partially developed whereby a settling ratio can be determined by a static test and this in turn related to the distribution of solids, or the concentration gradient, from top to bottom of a horizontal pipe cross-section.

The proposed settling rate test will distinguish between those suspensions that are easy or difficult to sample. A suspension can be withdrawn from a flowing stream and used in the test. Low values of the settling ratio mean that the suspension is insensitive to the method and rate of sampling, whereas high values show that the recommendations given above must be adhered to.

The recommendations related "settling factor" and concentration gradient to ease of taking a representative sample.

"Settling factor" is defined as the quotient of the dispersed phase that

moves more than 35.6 cm (14 in) in 1 minute, divided by the amount that moves less than 27.3 cm (10.75 in). Stokes Law calculations for oil and brine from WD45 show that a 205-micrometer oil drop will rise slightly more than the 27.3-cm and thus raise the settling factor from zero to infinity. Since the photomicrographic system is designed to an upper drop size cutoff of 100 micrometers, the "settling factor" may be considered zero. In one case, the effluent from WD45 Wemco, the pipe diameter times average flow equals 0.62 and the dispersed phase distribution (-m) for kerosene in weak brine is 0.08. Since the conditions of Section 5 above are exceeded, pipe wall sampling is predicted to give satisfactory results. It is also predicted that the much sparser dispersion of the oil phase and the much denser brine will both act to increase sampling reliability.

Appendix C details a field experimental approach to resolution of the question. The experimental data showed no clear difference between pipe wall and pipe center samples. One statistical treatment of the data showed average drop size depended upon sample point for the Wemco inlet, but not for the Wemco outlet. Since there is no clear-cut evidence that wall sampling alters the drop size dispersion, samples taken from pipe wall taps will not be rejected. However, when the opportunity permits (gate valves as sample ports), it is recommended that samples be taken from a probe inserted to the center of the pipeline. In any case, the valve must be fully open to reduce flow-induced shear. The PMS pressure reduction system is designed to handle the excess flow.

FLOW FROM PIPELINE VALVE TO STANDPIPE PRESSURE REGULATOR

The PMS design uses a 30- to 90-cm length of 12.7-mm-OD, 9.5-mm-ID plastic tube as a connection between the completely open pipeline valve and the standpipe. Any other connection would be equally suitable provided that the flow remains in the turbulent regime. The flowrate for a 200-mm head of fresh water applied to a 100-cm length of 9.5-mm-ID plastic tube was measured at 3800 cc/min. This, using brine data from Platform WD45, results in a Reynolds number of 9500, which is well into the turbulent regime. Moderate changes in the sample transmission line would not be expected to change the flow regime, but the operator must remain alert to the possibility of sample degradation.

CELL PRESSURE REGULATION

One of the design criteria was that the system operate under widely varying sample pressures. Additionally, a constant bypass sample flow had to be maintained near the cell inlet to assure that the sample had never remained static prior to admission to the microscope cell. Application of the standpipe overflow principle as shown in Figure 9 satisfied both of these requirements. Continuous sample flow enters the tee at the bottom of the system, flows up the center tube, overflows and falls to the vent. When the cell solenoid valve opens, part of the flow is diverted through the cell. This flushes the cell with freshly acquired sample that has been in turbulent flow since its diversion from the pipeline. The pressure upon the cell is maintained constant over a very wide range of pipeline pressures. This pressure reduction is achieved without sample compromise through restriction-induced shear.

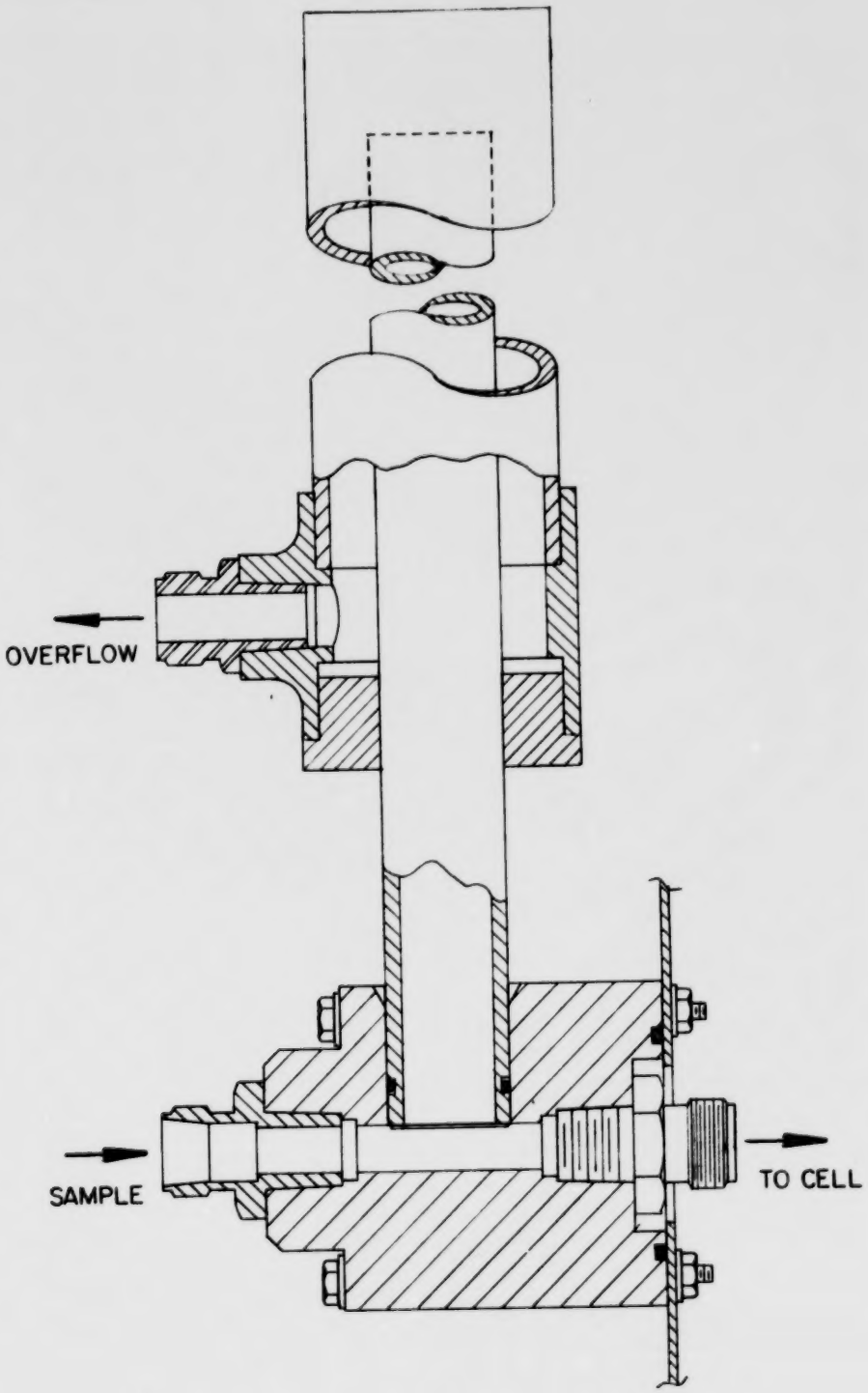

Figure 9. Standpipe pressure reducer.

CELL AND SOLENOID VALVE FLOW

The standpipe system is designed to establish a pressure equivalent to 21.5 cm of water at the cell inlet. Flow through the cell is interrupted by an altered (to permit wider opening) 9.5-mm Nacom Industries* Teflon diaphragm valve. When the valve was open to flush the cell with fresh sample taken from the standpipe flow, the flowrate was measured at 2075 cc/min. Reynolds numbers for such flow in the 4.5-mm-ID transfer tube and the cell body are 7600 and 4000, respectively. Both of these flows are well into the turbulent regime and the oil drop dispersion is uncompromised. Flow paths within the solenoid valve may induce shear, but this sample degradation occurs after the photographic cell and does not introduce error.

USE WITH OTHER SAMPLE SYSTEMS

The system was designed to sample low-pressure pipeline flows. It will function with pressures as low as 2.8 kPa (30 cm, 12-inch water) and has been tested to 44.8 kPa (457 cm, 15 ft water). Higher pipeline pressures will increase the standpipe overflow rate with only minimal effect upon cell inlet pressure. The PMS may be used with any sample source, providing sampling may be achieved without shear-induced sample alteration. Sample flowrate must be at least 3000 ml/min and ideally should be 5000 to 10,000 ml/min. The investigator must carefully consider the effect of pumps in the system prior to the cell. Pumps in the system after the cell will have no effect upon the sample except to reduce the pressure when in the cell. The serious effect of such pressure reduction is the release of gas bubbles from gas-saturated liquid and the expansion of already existent bubbles. This complicates data reduction and should be avoided. Additionally, the bubbles have been seen to change size or redissolve during the static period.

STOPPED FLOW PERIOD

Previous applications of the photomicrographic principle for measuring oil drop size dispersion relied upon the ability to photograph moving drops in a flowing stream. If one applies the requirement that the stream must be in continuous turbulent movement to eliminate sample stratification, the exposures must be extremely short. For example, the linear transit rate of a drop in the microscope cell at a Reynolds number of 4000 is 4.3×10^5 micrometers/second. Common shutters of 1/1000 of a second capacity would result in an image of a 1-micrometer-diameter drop that would be 430 micrometers long. Photography with an electronic flash lamp having a 50-microsecond duration would give an image 21 micrometers long. Even if the 5-microsecond "Strobotac" source were used, the image would still be twice as long as it was wide. We have established 0.1 micrometers as the desired limit of movement during photography. This would impose an exposure duration of 0.2 microseconds, which is beyond the range of available portable illumination sources. Accordingly, a stopped flow system was designed that would not induce sample degradation. The previous discussion of sample flow defends the assumption that the sample cell is filled with an uncompromised and uniformly dispersed sample at

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* See footnote 1, page 28.

the time turbulent flow is interrupted. Drop motion at this time is due to inertia and also to the random movement of turbulence. The sample must remain static until movement due to both of these sources dissipates and vertical movement due to density difference between the drop and the liquid matrix is established. Early work indicated that 4 seconds would be sufficient. However, reduction of a large number of photo triads where the static period prior to photography was 4 seconds showed that a longer static period would result in better density measurements. Therefore, a 10-second static period was used during the second field use. A change in cell dimensions over the original cell permitted this increase in static period without lowering the maximum drop size cutoff. It will be proven that this static period does not compromise the sample.

MICROSCOPE VIEWING CELL

The microscope viewing cell is the liquid volume in focus by the microscope optics. Its size is defined by the length and width of the film, the diameter of the drop (D) and the magnification and depth of focus of the objective. Under the conditions used in this work, the cross-sectional cell dimensions are 535 + D x 349 + D micrometers. The apparent depth of focus was found to be dependent on the drop diameter.

A slide of oil drops captured in gelatin was photographed with color film and electronic flash as used in the field studies. The microscope stage was moved in 4-micrometer steps over a wide range with photographs taken at each step. Twelve drops were selected ranging in size from 2 to 115 micrometers in diameter and the range of stage positions resulting in sharp-image photographs was determined by inspection of the photographs. The data were fitted to various equations with a Hewlett Packard statistics program found in their General Statistics, Volume 1, Part Number 09815, 15001. Equation 1 shows the best fit. This equation may only be applied under the exact conditions used in its determination.

$$\text{Depth of Focus (micrometers)} = 3.861 + (5.088 \text{ Ln Diam}) \qquad (1)$$

Black and white film, for example, gave significantly different results. The determination of "in focus" is very subjective and the data analyst must be well trained by inspection of the calibration photographs. Retraining by viewing the calibration photographs should be performed at periodic intervals to eliminate "subjective drift." There is a marked tendency to "find" drops in sparsely populated exposures which led to high drop counts and oil contents. The retraining minimized this effect.

Once the concept of the viewing cell as a boundaryless volume of liquid sample located someplace within the 25,000 x 3,175-micrometer cell is established, the preferred location may be selected. The objective side of the viewing cell is typically located 600 micrometers into the liquid to minimize the effect of the cell wall on drop rise. The top of the viewing cell is a nominal 1500 micrometers below the top of the microscope cell to avoid optical distortion from the cell curvature. If one discounts a 1000-micrometer section at the bottom of the cell, the drops may be said to have a conservative rise path of 22,000 micrometers to the bottom of the 535-micrometer-high viewing cell.

REPRESENTATIVE SAMPLE

The assumption has already been proven that the sampling procedures have placed an uncompromised and uniformly dispersed sample within the microscope cell when flow is interrupted. It remains to be shown that photographs taken 10, 10.3, and 12.0 seconds later capture a representative sample of the oil drops in the water. Figure 10 shows calculated rise distances in 10.3 seconds for oil drops in various matrices. Platform ST177 conditions resulted in the most rapid rise and therefore were used to prepared Table 2.

Referring to the 10-second column in Table 2, one finds that in this period a 2-micrometer-diameter oil drop rises 7 micrometers, a 100-micrometer drop rises 16,488 micrometers and a 125-micrometer drop rises 25,762 micrometers. As previously indicated, the free vertical rise section of the cell to the bottom of the microscope viewing cell is a conservative 22,000 micrometers.

Consider a zero time photograph where a 2-micrometer, a 10-micrometer, and a 100-micrometer drop are just inside the lower edge of the film image. The water sample had been stationary for 10 seconds before the photograph was taken and all oil drops had an opportunity to rise at their diameter and density determined rates for the 10 seconds. Thus the 2-micrometer drop had risen 7 micrometers, the 10-micrometer drop 165 micrometers, and the 100-micrometer drop 16,488 micrometers. Another way to say the same thing is that the 2-micrometer drop originated in a microvolume 7 micrometers below the viewing cell, the 10-micrometer drop in a microvolume 165 micrometers below the viewing cell, and the 100-micrometer drop, 16,488 micrometers below.

Considering the previously established fact that all drops are uniformly dispersed, all microvolumes have equal chances of containing any drop size. It therefore makes no difference if the 2-micrometer drops originate in one microvolume and the 100-micrometer drops in another. All microvolumes are equivalent and the sample volume photographed will still be representative of the entire sample.

TABLE 2. PLATFORM ST177 DROP MOVEMENT

(Brine Density = 1.151; Oil Density = 0.8418; Viscosity = .01021 Stokes)

Drop Diam., Micrometers	Rise Rate, Microns/Sec	Micrometer Rise in xx.x Seconds 10	10.3	11.7
2	0.7	7	7	8
10	16	165	170	193
50	412	4,122	4,246	4,823
100	1,649	16,488	16,983	19,291
125	2,576	25,762	26,535	30,142

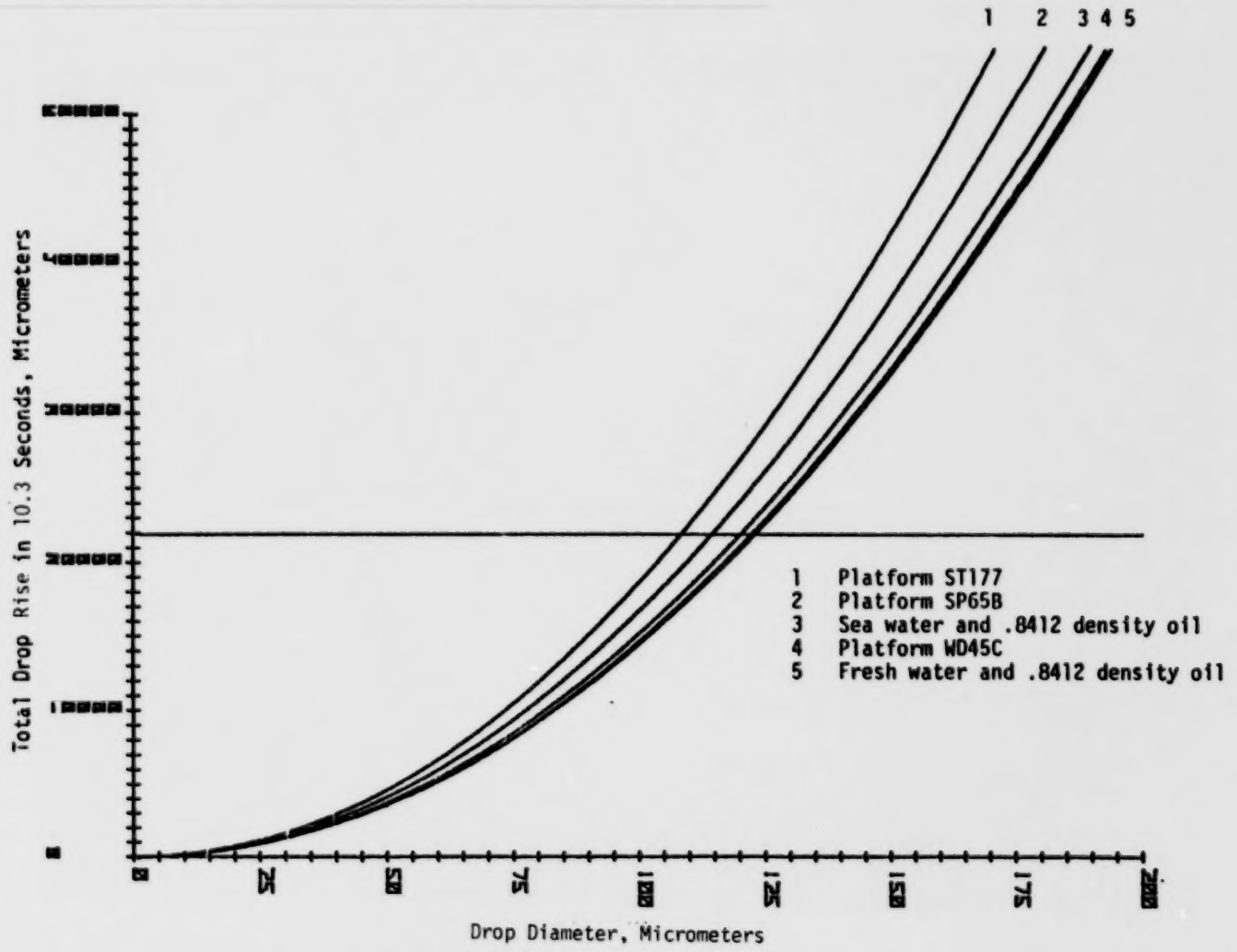

Figure 10. Drop position after 10.3 seconds.

This condition holds until the drop-rise distance during the static period exceeds the available path within the cell. This was defined as 22,000 micrometers and a 115.5-micrometer-diameter oil drop will then be the cutoff point, since it will rise 21,995 micrometers in 10 seconds. Any larger drops may exceed the rise path and, even if they originated in the lowest acceptable microvolume, may have escaped the viewing cell when the photograph was taken. Microscope viewing cell limitations indicate a conservative cutoff point of 100-micrometer diameter, and the above discussion shows that the viewing cell contains a representative sample at the end of 10 seconds. The rise rate is dependent upon water density and viscosity and oil density. Thus the actual cutoff point will change somewhat due to sample conditions.

Oil drop movement over a 12-second period is diagrammed in Figure 11. Column A diagrams the viewing cell, #1, at the top of the microscope cell and two equal-sized cells located below. Cell #2 is near the center of the microscope cell and #3 near the bottom. Each cell contains the same drop size distribution since the drops are uniformly dispersed throughout the cell. The drops carry the number of their cell of origin to permit following their movement. Column B shows the position of the drops 10 seconds later at the time of the first exposure of the time-lapse series. The large drops from cells 1 and 2 have risen out of view, but the large drop from cell 3 has been captured in the top, viewing, cell. The medium-sized drop from the viewing cell has escaped from view, but has been replaced by an identical drop from cell 2, the next lower one. The small drop's movements are minimal and each remains in its cell of origin.

Columns C and D diagram the drop position after 10.3 and 12 seconds. After 10.3 seconds, the large drop from cell 3 is still in view but is about to escape. It has, however, been photographed and its diameter and rate of rise measured and used to calculate density. Twelve seconds after flow interruption, the largest drop from cell 3 has escaped, the medium-sized drop originating in cell 2 and the small drop originating in cell 1 have moved measureable distances. Thus, although a drop may move out of the viewing cell, it is replaced by a drop of the same size from a lower volume and the photographs capture a representative sample of the oil drops in the microscope cell. This factor obtains until sufficient time has passed (12 seconds here) to allow the largest drop of interest to escape the viewing cell even though it was originally at the bottom of the microscope cell.

The preceding discussion of drop size cutoff applies only to the capture of a drop in a single photograph. Density measurement requires capture of the same drop in two photographs of the photo-triad to provide for measurement of rise rate. This requirement seriously decreases the effective vertical height of the liquid viewing cell because:

1. The camera motor drive limits successive photographs to 0.3-sec intervals.

2. During this time a 100-micrometer drop rises 495 micrometers.

3. Cell height - rise of drop = 40 microns.

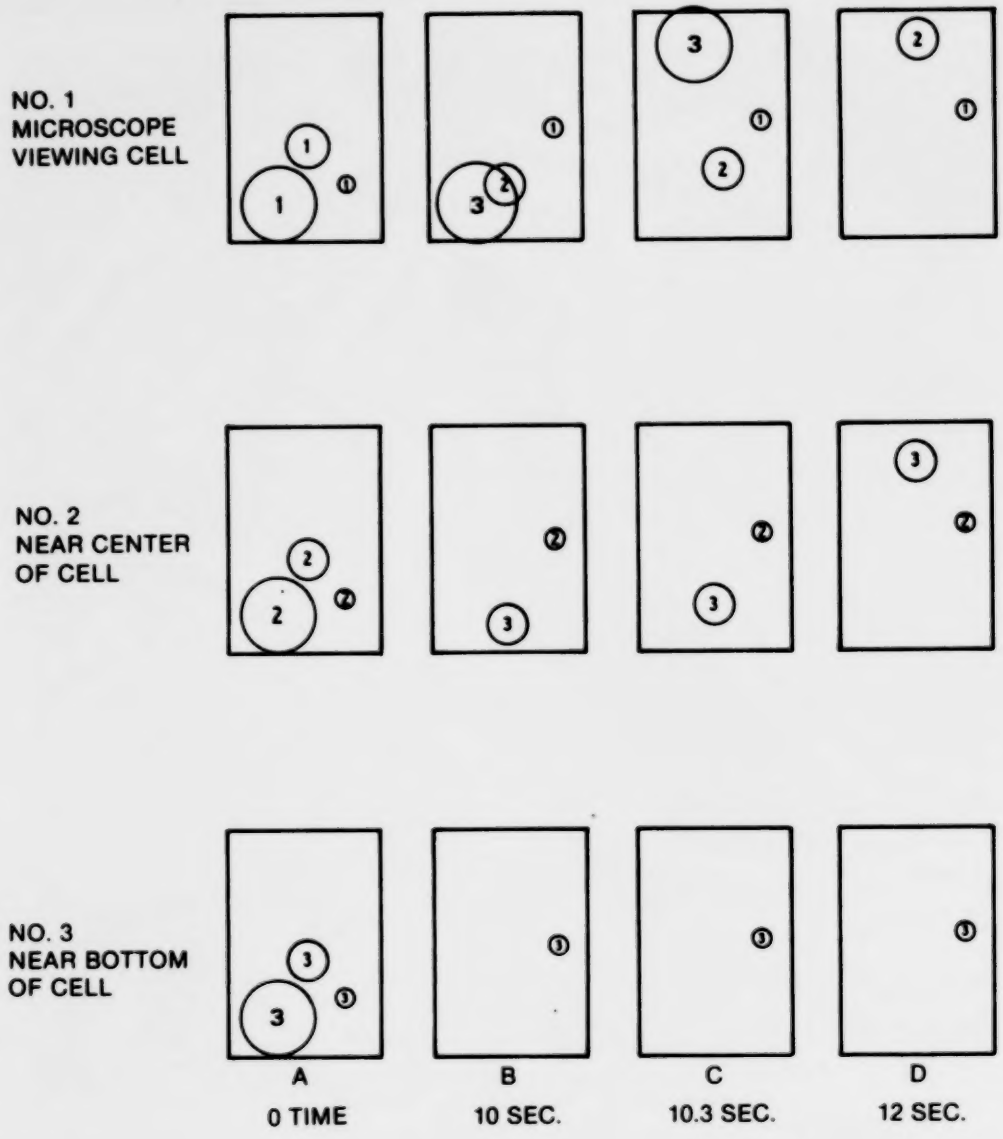

Figure 11. Drop movement during 12 seconds.

Thus a 100-micrometer drop has to be in the bottom 40 micrometers of photograph 2 to be at the top of photograph 3 taken 0.3 second later. Therefore, the effective viewing cell height for a 100-micrometer drop is only 40 micrometers. When a 50-micrometer drop is under consideration, the cell height is 411 micrometers. Thus the dynamics of drop movement as well as photographic aperture combine to fix the volume of the viewing cell during density determination. Understanding this factor is vital to the calculation of oil content based on the drop volume and the viewing cell volume.

There are many possible combinations of vertical position of the viewing cell within the microscope cell, static period prior to photography and time between photographs that will result in capture of divergent size and density entities. For example, if the viewing cell were positioned near the bottom of the microscope cell, the system would be optimized for entities heavier than brine. The photographic timing sequence has been optimized for oil drops. However, if the density measurement feature is eliminated, a photograph can be taken within 0.1 second of flow interruption and capture almost all entities in a single photograph. This is a switchable option in the PMS electronic circuitry. Such adaptations must be at the well-considered discretion of the user.

Density Calculation

Calculation of the density of the spherical body captured in two photographs taken known times is based on Stokes Law (Equation 1).

$$\text{Terminal velocity } (v) = \frac{g\ (\rho_m - \rho_B)\ D^2}{18n} \qquad (1)$$

where

g = acceleration due to gravity = 980 cm/sec^2

ρ_m = density of matrix

ρ_B = density of body

D = diameter of spherical body

n = viscosity of matrix (Stokes)

Measurement of the body's location in two photographs determine the vertical movement during the time-lapse period. Since the bodies reach terminal velocity very rapidly, the velocity may be represented by Equation (2).

$$V = \frac{d}{t} \qquad (2)$$

where:

d = vertical displacement of body between photographs

t = time between photographs

Substituting in Equation (1), then,

$$\frac{d}{t} = \frac{g\,(\rho_m - \rho_B)\,D^2}{18n} \tag{3}$$

and solving for ρ_B the density of the body (Equation 4)

$$\rho_B - \rho_m - \left(\frac{18nd}{g\,D^2 t}\right) \tag{4}$$

SECTION 5

DESIGN

The design of the PMS (Photomicrographic System) to implement the theoretical principles had to address several selection decisions as well as the mechanical portions of the system.

PHOTOGRAPHIC CONSIDERATIONS

The photographic equipment and operations presented were selected as cost-effective optimizations for the problem at hand. They have worked well in field use but may be changed at the discretion of future operators of the equipment. The rationales for their selection are discussed by equipment type in the following paragraphs.

Camera

The camera is an Olympus OM1 purchased without a lens. It is supplied with both a 36-exposure back and a 250-exposure back. The 36-exposure back is convenient for laboratory work and the 250-exposure back is used for field work. Film was purchased in 100-foot rolls that filled three 250-exposure magazines. The normal viewing screen was replaced with a No. 1-12 screen. This screen has a clear section with a cross etched in the center. It is designed to facilitate critical focus. A Varimagni finder is supplied to further ease the task of focusing. The camera is equipped with an MD-1 power film advance unit. This system advances the film and recocks the shutter. It will cycle in 0.3 second. A fully charged battery will run 1000 exposures and was exchanged for a fully charged one every 750 exposures. The camera has taken more than 20,000 photographs with only two areas of malfunction. The cam used to clamp the 250-exposure back to the camera body developed excessive play. This allowed the film to "jump" the drive sprockets. The result is that frames intermittently overlapped each other by distances equal to one or two sprocket holes. The malfunction was rectified in the field by placing pieces of electrician's tape on the clamp surface. The manufacturer has repaired the system and it has operated faultlessly for 10,000 photographs. The flash synchronization contacts failed at about 19,000 operations and required cleaning and adjustment.

Film Selection

The system is designed for 35-mm film in 20- or 36-exposure cartridges or 33-foot continuous lengths. The 33-foot lengths are cut from 100-foot rolls and loaded into the special magazines by the operator. The exposure given the film is a system parameter that is beyond the casual control of the operator. It can be easily decreased by the use of neutral-density filters or improper optical

alignment, but cannot be increased.

ASA 200 Ektachrome film in 100-foot rolls was selected for the field study. Several other films were tested such as Plus X and Super XX black and white, and 5247 color negative film. The black and white negative films were difficult to digitize since the oil drop images were of low contrast. The 5247 film would have been satisfactory after positive slides were made, but the processing was nonstandard and it proved difficult to locate a satisfactory processing laboratory. The Eastman Kodak Ektachrome is a standard film of high quality and reliability. A film processing laboratory was located in Hollywood, California, that offered a 3-hour processing service. Ektachrome is available in several emulsion speeds. The ASA 200, the fastest available in 100-foot lengths, was chosen to match the illumination of the Sunpak 611 photo-strobe unit used in the first field study.

The film speed requirements have been changed for future work because of a change in the lighting source.

The system, in its present configuration with Strobotak illumination, provides proper exposure of clear to slightly tan liquid samples when the film has an ASA rating of 800 to 1600. The strobe illumination has a higher blue content than daylight and thus produces blueish-colored transparencies. If precise color rendition is required, optical filtering may be applied. The electronic system is still capable of operating an electronic flash gun such as a Sunpak Auto 611. In this case, recycle time limitations would apply, but film speed requirements would be greatly relaxed. Such system alterations should be placed in the hands of a capable electronics engineer.

The system was last used with Ektachrome ASA 200 professional film #5036. The film was push-processed for a three-stop underexposure that raised its effective speed to ASA 1600. An Arkay 100-foot processing tank was used because no commercial continuous process machine with three-stop push capability could be located. In the Arkay tank, the film is wound from one reel to another and has very limited chemical contact time. E6 processing in this system is not recommended and the results, while usable, were not up to normal photographic standards. The problem seemed to reside in the time allowed for the bleach, clear or fix steps. It is possible that processing times could be adjusted, but it is doubtful that such a study would be cost-effective. The film could be cut into six 36-exposure lengths and processed in tanks such as the 22-inch Omega tank that will process 16 such strips at a time.

The Superior Bulk Film Co. (442 N. Wells Street, Chicago, Illinois 60610) lists a tank and reel processing system called the "Soligor/2080." The system is designed for 32-foot, 250-exposure film strips. The 1980 catalog price is $213. This system has not been used by the author, but is recommended for consideration. High-speed black and white film is available in 100-foot and larger rolls. However, laboratory and field experience indicates that color film is a much better choice. The recommended films available in 100-foot rolls are:

1. Eastman Ektachrome 200 professional film #5036
2. Eastman Ektachrome Video News Film ASA 160 #5239

3. Eastman Color Negative Film ASA 100 #5247

4. Eastman Video News High-Speed ASA 400 Tungsten #7250. This is a special-order film. Minimum order is 430 100-foot rolls at $53.26 each (May 1980).

All of these films must be push-processed to increase their speed.

One other caution is worthy of comment. Some of the Ektachrome 200 film was found to be very hygroscopic. When exposed to the high humidity of the Gulf of Mexico region, it became so sticky that the sprocket holes would tear out before the film would unroll. The problem was alleviated by loading the film into the magazines and the magazine into the camera in the dehumidified atmosphere of the control room. The loaded camera was placed in a plastic bag for transport to the sample point.

Illumination Source

The first field study was performed using a Sunpak 611 photographic strobe light. The strobe is an automatic thyristor-controlled unit and was used in the 1/128 power ratio position. The thyristor shut off the power flow after 1/128 of the total capacity had been discharged. The system then recharged to full capacity in 0.25 second. Thus, the strobe was ready for a second flash within the 0.3 second available between photographs 1 and 2. In actual practice, slight exposure differences between the photographs in a triad were evident. The flash duration was rated at 1/50,000 second, or 20 microseconds. This proved to be completely satisfactory and no motion-blurred photographs were found. This was true even when the system was operated in a high-vibration area on a production platform near large pumps.

After the first field study it was decided that system operation could be improved by changing the illumination source. A General Radio Strobotac unit was modified to operate from a 12-volt battery and used in the final system. This unit has a flash duration of less than 5 microseconds and recycles within a few milliseconds. While the 20-microsecond flash was satisfactory, the 5-microsecond unit adds additional versatility in photographing drops in motion. The major advantage of the Strobotac, however, is in operation from the system battery and a significant decrease in weight. The more significant disadvantages of the Strobotac's low illumination levels, which mandated special film processing, leads to a recommendation that the Sunpak illumination be reinstalled. Another option would be the employment of a detachable-head electronic flash having the same power and recycle character as the Sunpak. This would eliminate the requirement to alter the Sunpak to make it fit the second operational case.

MICROSCOPE CONSIDERATIONS

The microscope system was originally an Olympus BHA-100 microscope with 4X, 10X, and 20X Plan Achromat objectives, a BH-SHR stage, and suitable eyepieces for viewing and photography. In the final version of the system, much of the microscope was eliminated because it was nonessential and heavy. The base, including part of the illumination system, and the mechanical stage were

thus eliminated. The substage condenser system was retained. The unconventionally high position of the viewing cell precludes any attempt to establish Koehler illumination conditions. Despite the violation of most conventional microscope illumination practices, resolution was sufficient to clearly define 2-micrometer-diameter oil drops on the film. The validity of the definition and calibration was substantiated by photography and measurement of known 7-micrometer-diameter pollen suspended in a liquid matrix.

Proper focusing of the microscope is a critical factor in the successful application of the system. However, since the viewing cell may be located anywhere within the 3000-micrometer width of the microscope cell with equally satisfactory results, a reasonably wide latitude of focusing exists. The focusing system of the microscope is well calibrated and each revolution of the fine-focusing knob moves the stage 200 micrometers.

A complete description of the focusing procedure is found in Section 6, Operating Instructions. Briefly, it consists of successively focusing the microscope on a piece of tissue placed on the cell, raising the cell until the outer cell wall is in focus, raising further to focus on the inner cell wall, and then raising the cell a calibrated distance to place the focal zone within the liquid volume.

INSTRUMENT CASE

The case is constructed in two parts. The lower part is constructed of aluminum sheet riveted to a strong internal frame. This part contains all gas and liquid ports and switches (Figure 5). All joints are completely sealed and a gasketed flange is provided to mate with the upper section. All internal components are securely mounted to this section.

The gas ports consist of the pressurization gas inlet and the reference port for the pressure safety switch. This switch interrupts all internal power until a pressure of 1.2 kPa (5 in. H_2O) is established. The liquid port is the sample outlet. The sample inlet standpipe block is attached to the opposite side of the case. A bank of hermetically sealed switches is provided to control the function of the system. They will be described under the Electronics heading.

The upper part is constructed of Acrolite, a clear plastic. It mates with the lower part with a leakproof seal to contain the pressurizing atmosphere. It is secured in place with eight suitcase-type latches.

SOLENOID FLOW CONTROL VALVE

Nacom (1) 9.5-mm (3/8-in) all-Teflon diaphragm valve was operated from the 12-volt supply to provide flow control. The return spring and diaphragm were modified to permit maximum opening. The valve used with the Vitrodynamics (2) cell was similar, but with a 6.4-mm (1/4-in) port which resulted in a

(1) Nacom Industries, 2852A Walnut Avenue, Tustin, California 92680.

(2) Vitrodynamics Co., 114 Beach Street, Rockaway, New Jersey 07866.

reduced flow.

CELL

Two cell configurations are interchangeable. One, the original design, consists of a 1.0-mm path length, 1-cm-wide Vitrodynamics Macromicroslide cemented into altered 1/2-inch Swagelok fittings. This cell configuration, Figure 12, causes significant flow restriction and requires a 36-inch standpipe for proper operation.

Many sample sources provided insufficient pressure to overflow a 36-inch standpipe and the second cell configuration was developed. This cell, Figure 13, is constructed of Acrolite plastic in a machined and cemented configuration.

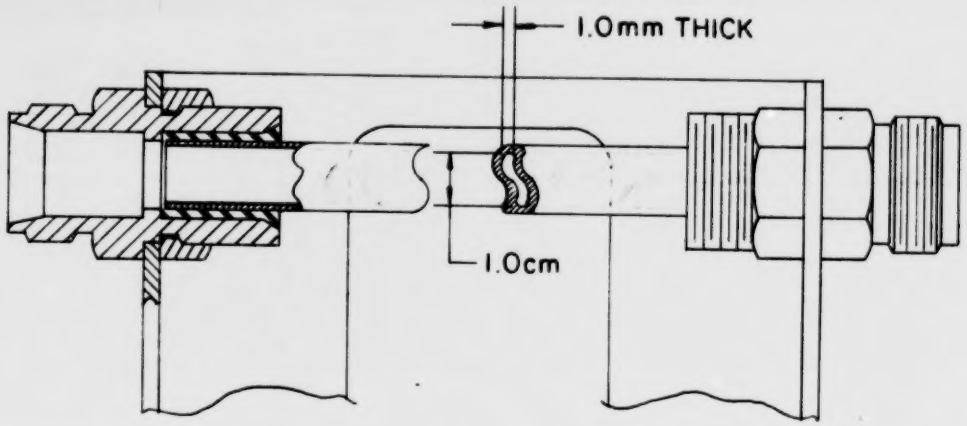

Figure 12. Macromicroslide cell.

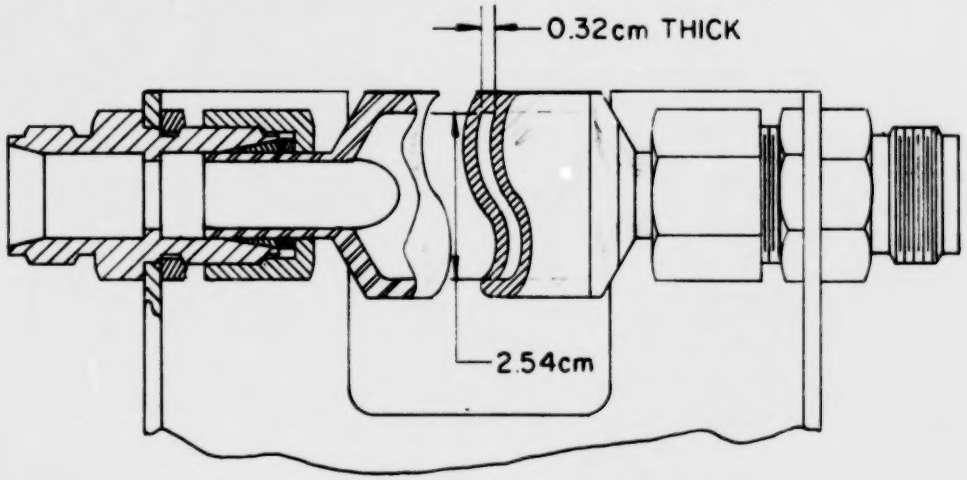

Figure 13. Plastic cell.

The internal dimensions in the viewing area are 2.5 cm high, 0.32 cm thick, and 2.5 cm long. The low flow restriction of this cell, combined with the larger solenoid valve, allows operation with a 21.5-cm standpipe.

PRESSURE REGULATION STANDPIPE

The sample supply pressure varies widely between sample points and a fresh sample must always be available at the cell inlet. A standpipe overflow system, Figure 14, operated in the bypass flow mode fulfills both of these needs. The connection block is constructed of Teflon and is mated to the lower case section with an O-ring seal. The PVC standpipe section is a friction fit and O-ring sealed connection into the top of the connection block. It is self-supporting. The flowing sample contacts only Teflon until it is used or past the cell port.

POWER SUPPLY

With the exception of the camera motor drive, the entire system is powered with a single 12-volt battery. The battery selected is an Elpower (1) Model EP1250, 12-volt, 5.0-a.H rechargeable solid-gel battery. Its dimensions are 150 x 63 x 95 mm and it weighs 2.27 kg. The battery fits snugly into a foam-cushioned battery case.

A fully charged battery has ample power to run the system for the 1.5 hours required to make 750 exposures (3-33-foot magazines). Field practice was to exchange the battery for a fully charged one at this time. A multiple battery charger, described in the Electronics section, is supplied for recharging in a safe area.

ELECTRONIC CONTROL SYSTEM

The electronic control system is composed of four major subassemblies, interconnected by flexible cable/plug assemblies. Each assembly is independently removable from the main frame for service or adjustment. The system is diagrammed in Figure 15.

Primary Power

Operating power is supplied by a rechargeable, 12-volt, 5-ampere/hour gelled electrolyte battery. The positive terminal of the battery is wired through a pressure-operated switch (normally open) that requires a minimum pressure equivalent to 1.2 kPa (5 in. of H_2O) to close. Pressure is supplied to the main enclosure by an external inert gas source, and insures compliance with Group I, Section 1, Class D requirements. The useful life of a charged battery is in excess of 2 hours. They are normally exchanged for a freshly charged battery after three rolls of film, or 1.5 hours. The system is diagrammed in Figure 16.

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(1) Elpower Corp., Santa Ana, California.

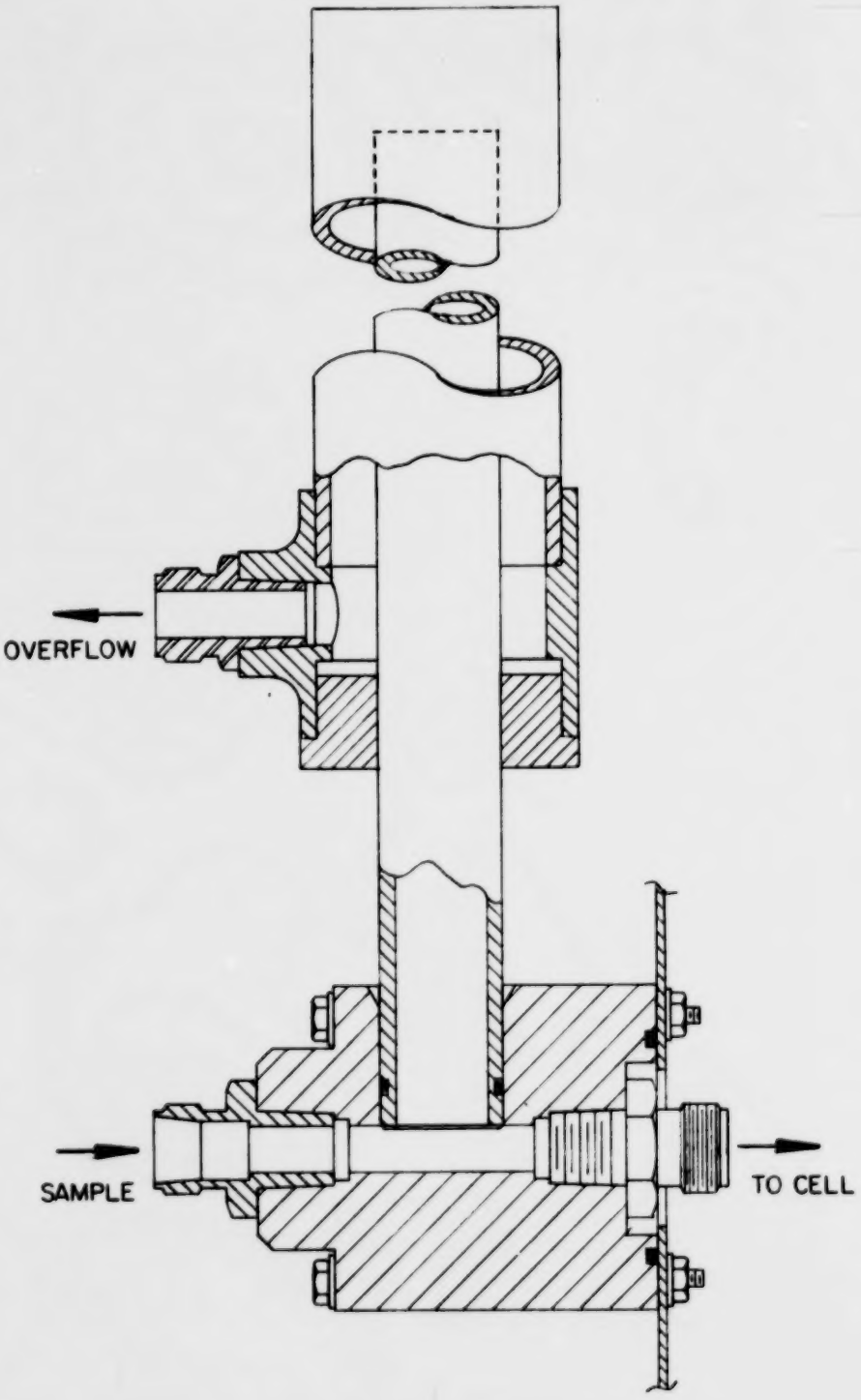

Figure 14. Standpipe pressure regulator.

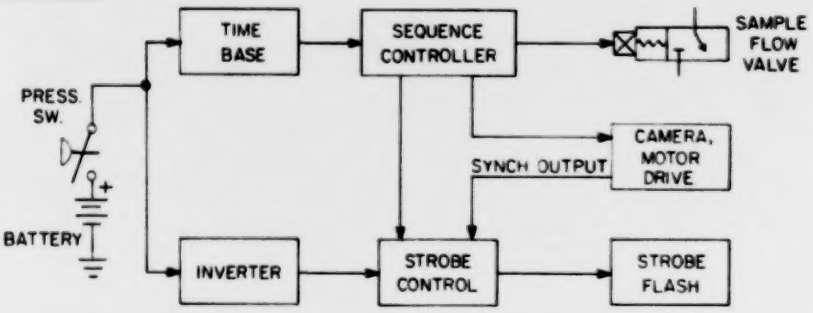

Figure 15. Electrical block diagram.

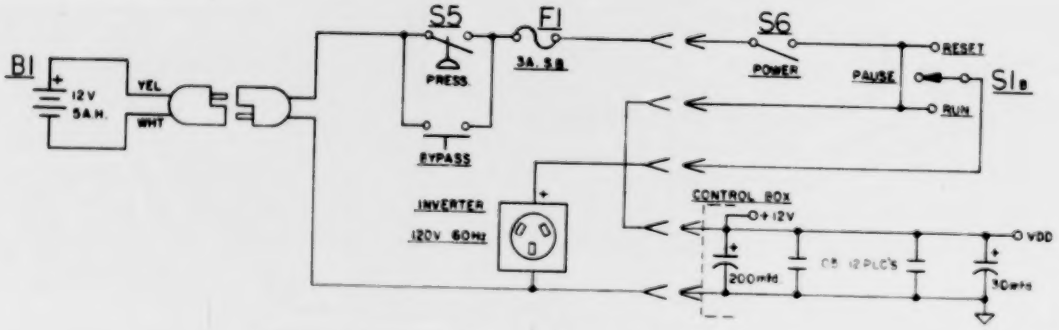

Figure 16. Primary power diagram.

Flash Tube Power Supply and Control

NOTE

This power supply is floating above ground and develops potentially lethal voltages.

A commercial inverter is used to convert the 12-volt DC primary power to 120-volt AC, square wave, at approximately 60 cps. This power is supplied to the strobe control circuit, Figure 17. The output of the inverter is zener-diode-clamped at 120 volts peak, to provide a constant voltage, over the useful discharge range of the primary power source. Figure 16 shows the strobe primary power supply circuitry.

The output of the inverter supplies power to the flash tube power supply and control assembly which powers the high-intensity gas discharge flash tube.

The inverter is a major drain upon the power supply battery. Accordingly it is wired to the timer external control switch. The inverter is on only when the timer is in the RUN or RESET positions. The on time should be limited to actual use time to conserve the battery.

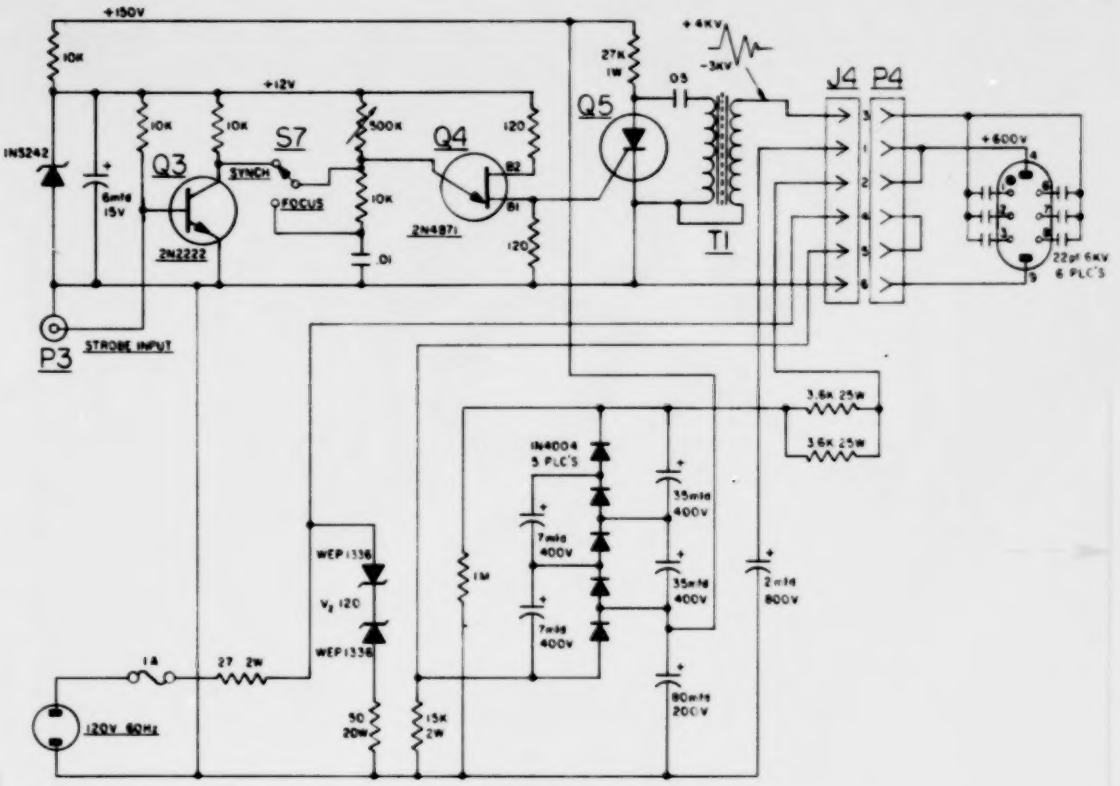

Figure 17. Strobe power circuit.

The gas discharge flash tube is powered from a voltage quintupler circuit, composed of five diodes and six capacitors. The 120-volt, 60-Hz squarewave input is raised to approximately 600 volts and stored in a 2-mfd capacitor.

Tube firing is initiated by a 4000-volt pulse, capacitively coupled to six dynodes located within the flash tube and between the anode and cathode. The firing pulse results from discharging a charged 150-volt capacitor. This is accomplished through the trigger transformer by firing an SCR connected in series with the transformer primary.

The SCR gate is controlled by a uni-junction transistor which, by switch selection, may be made to oscillate at 50 to 100 Hz, or provide a single pulse when an additional NPN transistor base is connected to the power supply common.

In the oscillating mode, the flash tube supplies an essentially constant light source for focusing and optical adjustment.

In the single-flash photographic model, the camera sync contacts cause a relay closure in the timing control module. This relay action causes the above transistor base switching and fires the flash lamp.

Time Base

The circuit, Figure 18, utilizes CMOS, digital integrated circuits. UI is a crystal-controlled oscillator at 2.048 MHz, and a 4098:1 divider. This drives U2, a 10:1 divider.

The output of the timer oscillator is a symmetrical 50-Hz square wave. This signal therefore includes a positive-going pulse every 20 milliseconds. Three-decade ring counters, U3, U4, and U5, are connected in series to count these positive-going oscillator pulses. Each of the 30 decade counter outputs is connected on a patchboard to a separate bus of 10 commonly connected wire sockets. The sockets are used to connect jumper wires to cause the several triple input NOR gates in the logic control circuit to function in the desired time sequence and sequence the several automatic actions of the system. The busses are arranged left to right viewed from the top 0-9, 00-90, and 000-900. Each decade is identified by the standard RTMA color code. There are two additional busses: "low," identified by double green marks, and "hi," identified by double black marks.

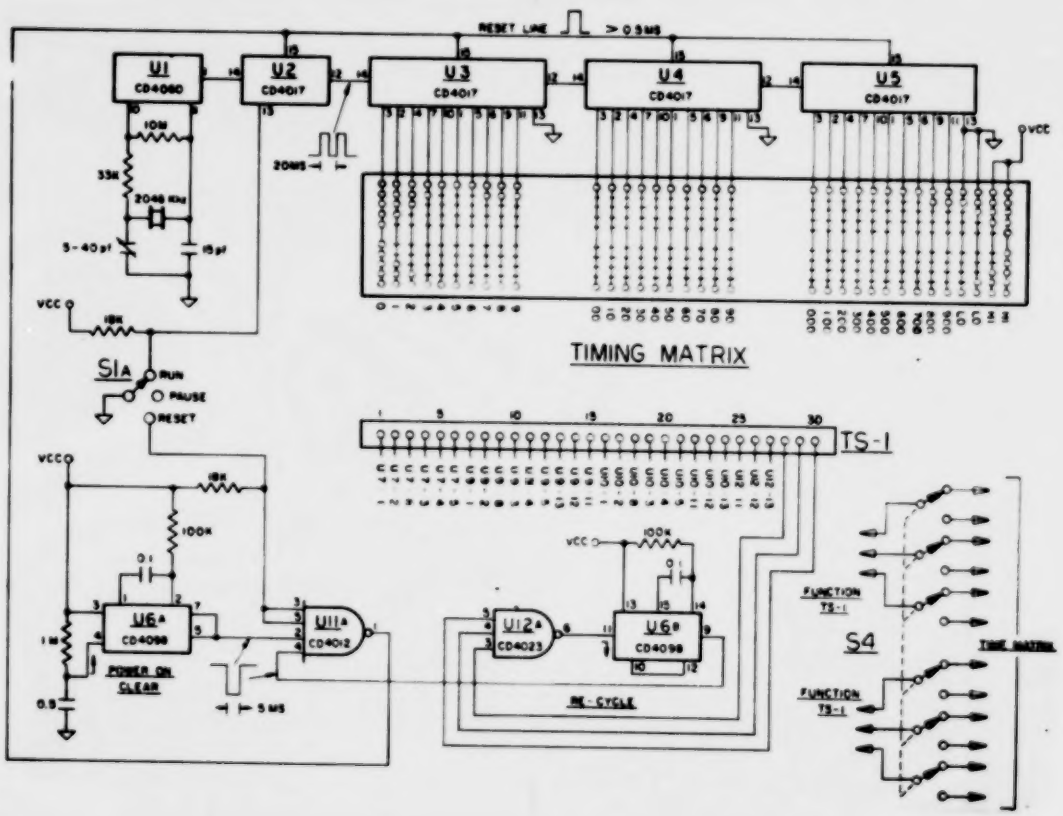

Figure 18. Time base circuit.

U11 is wired as a triple input, NAND gate, and provides a reset pulse to the entire counter chain when one or more inputs go "lo." This sets all counters to "0."

One half of U6, a single-shot pulse generator, provides a 5-ms "lo" pulse, 50 ms after "power on," to U11, to set all counters to "0."

Upon completion of the reset operation, bus lines 0, 00, and 000 are high and all others are low. The first oscillator pulse drops the Ø bus low and raises the 1 bus high. The second drops the 1 bus low and raises the 2 bus high. The 10th pulse "cycles" the first counter, U3, causing the 0 bus to go high once again. It also transfers one pulse to U4, the second decade counter. This causes the 00 bus to go from high to low and sets the 10 bus high. The next time the 0-9 counter "cycles," it sets the 10 bus low and the 20 bus high. This sequence of operations continues, cycles U4, advances U5 from 000 to 100, continues, and, after 999 pulses or 19.98 seconds, cycles counter and starts over. This restart is never allowed to occur since the RESET line is always programmed to recycle the system in less than the 19.98 seconds.

Logic Control Circuit (Figure 19)

All auxiliary functions are initiated by the application of three simultaneous "hi's" to triple input NAND gates shown in Figure 19. The interconnection between Figures 1 and 8 is at terminal strip TS1.

All control function inputs are wired in triplicate to the terminal strip, located parallel to the main timing matrix board, and coded per RTMA color code, which is as follows:

Brown: solenoid start

Red: solenoid stop

Orange: camera shutter

Yellow: camera shutter

Green: camera shutter

Blue: strobe

Violet: strobe

Slate: strobe

White: strobe

Black: recycle

Programming--

Times are selected from 000 to 999 increments of 20 ms, and three jumpers inserted between the time matrix and the functions as required. Unused

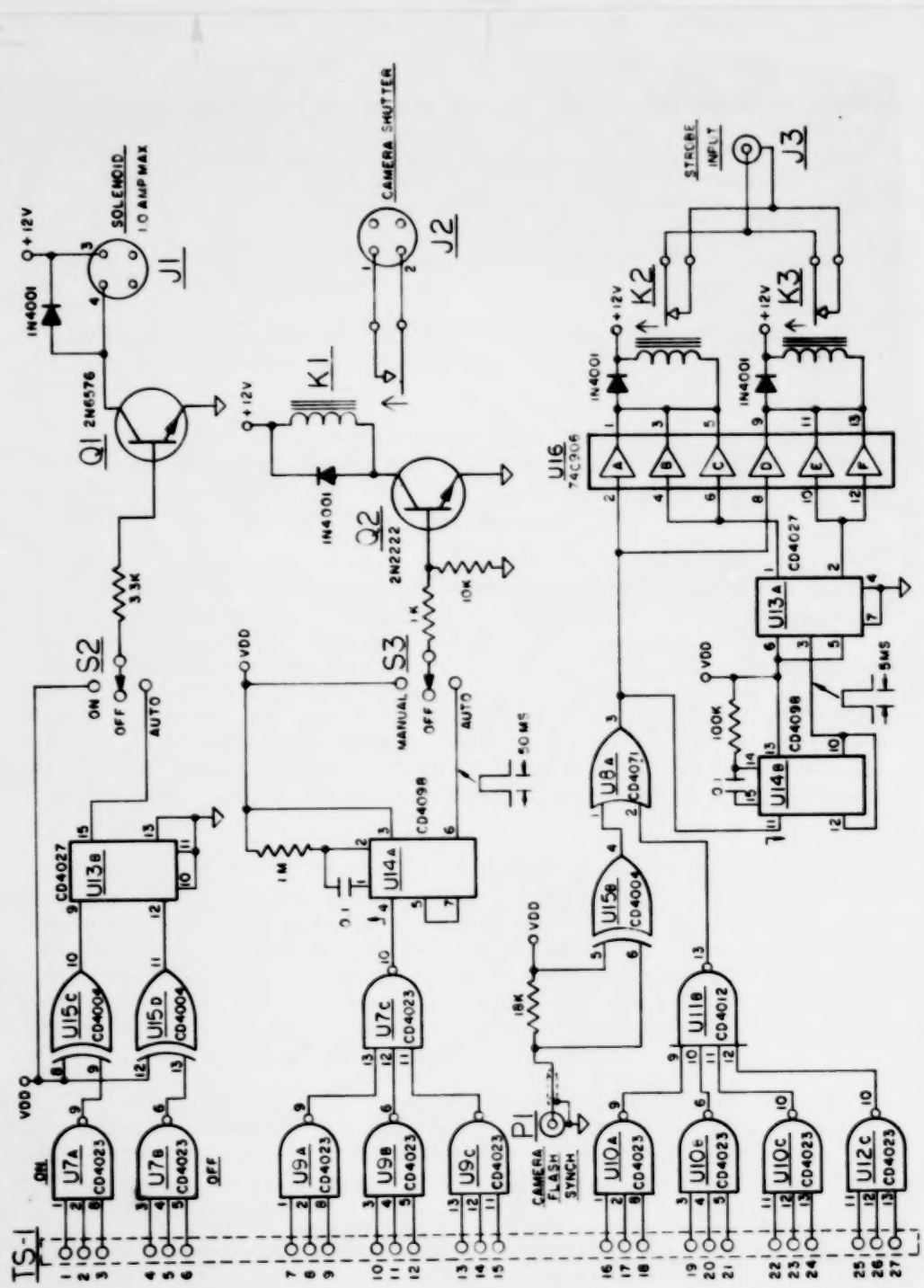

Figure 19. Logic control circuit.

functions must have one or more leads inserted in the double green (logic "lo") buss to disable them.

Solenoid Start--Three simultaneous "hi's" to the input of one-third of U7, a triple input NAND gate, provide a "lo" to the input of one-fourth of U15, wired as an inverter. The output of U15 produces a "hi," which "sets" the set input of one-half of a J/K flip-flop (U13), producing a "hi" at the "Q" output. This output goes to a SPDT switch, S2, with three positions, Continuous, off, and cycle. In the cycle position, this output of U13 is applied to the base of a Darlington transistor "Q1" which completes the circuit, energizing the solenoid.

In the off position of Switch 2, the solenoid is disabled. In the "Cont" position the transistor base is driven from +12V DC, and the solenoid is on continuously.

Solenoid Off--The application of three "hi's to another one-third of U7 drives an additional one-fourth of U15, providing a "hi" to the "R" input of U13, setting the output to "lo," turning Q1 and the solenoid off. The system is capable of supplying 1 amp at 12V DC.

Camera Shutter--The camera shutter may be fired at three sequential times, selected by application of three simultaneous "hi's" to each section of U9, a triple-triple input NAND gate. Simultaneous "hi's" to any triple input of U9 results in a "hi" from one-third of U7, provided a "hi" to half of U14, a single-shot multivibrator with a "hi" pulse of 50 ms. The pulse goes to the AUTO position of S3, an SPDT switch, which selects AUTO, off, and single. In the AUTO position, the output of U14 drives the base of an NPN transistor (Q2) positive. The transistor operates relay (K2) and a pair of normal open contacts tripping the camera shutter and motor drive. In the off position, the camera is deactivated, and in the single position the camera is fired, once for each switch closure.

Strobe Timing--The strobe may be fired by the camera sync contacts, the timer controlled signals or by a combination of both. This capability remains from development work and has not been removed. At present, one line of each of the four strobe firing circuits is connected to the lo bus (double green) to disable them. The strobe is fired in synchronization with the shutter by connecting a sync cable between the camera and the circuit input marked camera flash sync. The contact closure operates through two sections of U15, an exclusive OR gate, to produce the control action.

The strobe may also be fired at any of four selected times by wiring "hi's" to the inputs of the selected three-input NAND gates, U10 or U12. These gates output a "lo" to the input of a quad input NAND gate, U11, which provides a "hi" to the input of one-fourth of U8, an OR gate.

The output of U8 provides a "hi" to three paralleled inputs of U16, an open collector buffer. The open collector output provides a ground return for the coil of relay K1. When the U16 output goes "hi," the relay is de-energized, closing a pair of NC contacts, which grounds the base of the NPN transistor in the strobe firing circuit. Any unused gates must have at least one input wired to the "lo" buss, double green, on the patchboard matrix.

Table 3 details the three- photograph time-lapse sequence used in the last field study and the timing connections that generate the sequence. Using the "solenoid valve close" step as a programming example and expressing all times in seconds after reset:

The valve is to close at 5 seconds

5 seconds divided by .020 second per pulse = 250 pulses

Connect line 1 to a 0 wire socket

Connect line 2 to a 50 wire socket

Connect line 3 to a 200 wire socket

Line 1, line 2, and line 3 refer to the three control lines of the triple-input NAND gate controlling the valve off function (coded red on the patch panel). When all three lines are "hi" the controlled action occurs. Figure 20 shows the signal versus time curve for the three wire socket groups used. With reference to timing in oscillator pulses which are 20 ms apart, the 0 wire sockets are turned from their initial hi state to lo by the first pulse; the sockets are returned hi by the 10th pulse and maintained hi for one pulse (20 ms). This action is repeated every time the units decade counter cycles. In a similar manner, after the units counter has cycled five times (50 pulses) and transferred five pulses to the 10's counter, the 50 wire sockets are set hi. They stay hi until the units counter completes another cycle (requiring 200 ms) which returns them to low. The 200 wire sockets operate in the same manner and are controlled by the 10's counter. They are driven hi during the second cycle of the 10's counter after a lapsed time of 4 seconds and remain hi until the third cycle of the 10's counter 2 seconds later. The dashed line on Figure 20 indicates the state of all three wire socket groups during the 250th pulse and it can be seen that all are hi. This satisfies the control requirement of the NAND gate and closes the valve.

Single-Shot Time-Lapse Selector--

S4 is a 6-pole, 2-position switch mounted on the time base circuit board, Figure 18, to permit rapid switchable transition between two timing sequences. It is designed to select either three photograph time-lapse photography or to take a single photograph of each water sample. In the time-lapse mode, the camera shutter is controlled by the three timing circuits (orange, yellow, and green) previously discussed and the recycle time by the black. In the single-cycle mode the camera and reset times are controlled by additional lines from the switch to the timer matrix. The system timing was selected to maximize sample throughput. The valve action is unchanged at 5 seconds flush time, but the camera is fired at 5.1 seconds and the recycle set at 5.2 seconds. Thus a 250-exposure roll of film is exposed in 23.7 minutes in the time-lapse mode or in 21.7 minutes in the single-shot mode. In the first case, 83 water samples would be photographed and in the second, 250.

Battery Charger

A separate battery charger, Figure 21, is supplied to simultaneously

TABLE 3. FIELD STUDY TIME-LAPSE SEQUENCE

Step Description	Bus Color	Secs.	Pulses	Line 1	Line 2	Line 3
Solenoid Open	Brown	.021	1	1	0	0
Solenoid Close	Red	5.00	250	0	50	200
Camera Shutter 1	Orange	15.00	750	0	50	700
Camera Shutter 2	Yellow	15.30	765	5	60	700
Camera Shutter 3	Green	17.00	850	0	50	800
Reset	Black	17.10	855	5	50	800
Strobe 1	Blue					
Strobe 2	Violet	Unused - camera contacts fire strobe.				
Strobe 3	Slate	All line numbers are connected to the low - double green bus.				
Strobe 4	White					

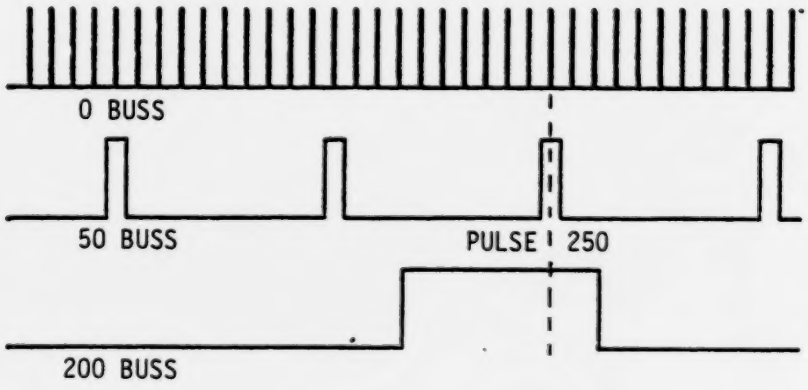

Figure 20. Timing pulses at the output busses.

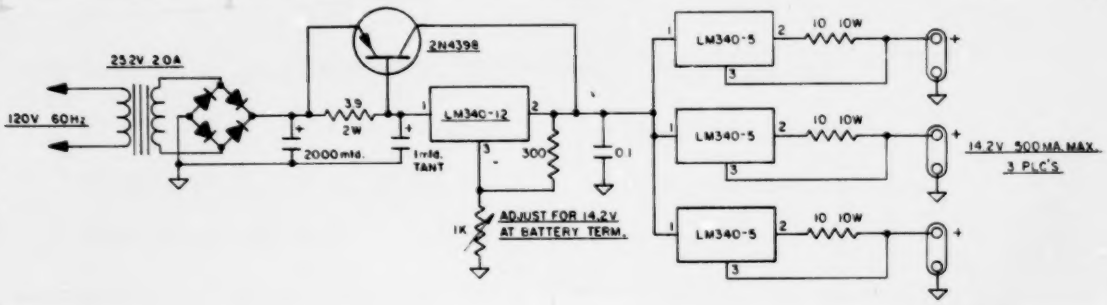

Figure 21. Battery charger.

charge one to three "Gel-Cell" batteries. The charger is operated from 120V AC in a safe, nonexplosive-atmosphere, area. A transformer and bridge rectifier provide 25.2 volts DC at 2.0 amps to the system. The DC voltage feeds a hybrid voltage regulator, shunted by a PNP pass transistor. The regulator output is adjustable, to provide a nominal 14.2 volts at the battery terminal.

Three current regulators are connected between the voltage regulator output and the respective battery cable connectors. These current regulators are composed of hybrid voltage regulators, wired as current regulators by sensing the voltage drop across series sensing resistors. Each current regulator limits the current to 500 ma.

This charger provides a taper charge characteristic that insures a full charge within about 6 hours, but prevents overheating or overcharge of the batteries when left on the charger beyond their full charge time.

Unused Components

This system is the result of a long development program and has not been rebuilt to eliminate unused features. Accordingly, when the circuit boards are compared with the schematics, extra components will be found. Their functions have been disabled or they have been removed from the electronic system. Some unused functions such as the four timed strobe firing options have been made nonfunctional by connecting one of the three NAND gate inputs to a permanent "low." The presence of these components and functions does not impair the operation of the system, which has been well field-tested.

CALIBRATION

Photographs of a stage micrometer are used to calibrate the system. A stage micrometer is a glass plate with a very precise scale etched into its surface. Divisions and subdivisions differ widely and the one chosen for the oil drop study has 10-micrometer subdivisions. Ealing Corp., South Natick, Massachusetts, lists stage micrometers with 2- to 100-micrometer subdivisons. The calibration is a one-time laboratory operation and need not be repeated unless the objective, eyepiece or microscope tube length are changed. The stage micrometer was placed in the microscope focal plane and several exposures were made. These films were then retained for projection during data reduction.

An additional calibration experiment has been made to verify the stage micrometer calibrations. Three size classes of spores were purchased from Duke Scientific Co., Palo Alto, California. They included:

#419 Bermuda Grass smut spores	7-micrometer diameter
#213 Paper Mulberry pollen	13-14 micrometer diameter
#396 walnut pollen	40-50 micrometer diameter

A water matrix containing these spores was generated and photographed in a flowing system. Data from 55 exposures are presented in Table 4.

This calibration effort showed that the stage micrometer calibrated data agree well with the values measured by the suppliers. Time constraints precluded a longer study to completely test the system calibration.

DATA REDUCTION

Data reduction can assume several configurations, dependent upon the volume of photographs to be studied. Two techniques will be discussed. One requirement is common to all techniques. The entire photographic image must be studied. Normal 35-mm color transparencies are mounted in plastic or cardboard holders. The inside edges of the holder obscure a small portion of the image. The amount and position of the obscured edge is a variable with no control by the operator. Since density determination depends upon precise measurement of the drop position relative to a lower corner of the photograph in two time-lapse photographs, the error caused by variable mounting cannot be tolerated.

A glass-type strip film holder was designed to fit a Kodak 500 projector. Movement of the glass pressure plates was controlled by two solenoid actuators. The aperture of the projector was enlarged over the standard size to permit projection of the borders of the photographic image. Thus all positional measurements may now be referenced to the camera aperture.

TABLE 4. CALIBRATION DATA

Group	Spores Counted	Average Reported Diameter (Micrometers)	Measured Average Diameter (Micrometers)
1	8	7	6.5
2	14	13-14	13.8
3	3*	40-50	32.7

* These spores were out of focus and are included for general information.

The calculations of drop size dispersion and the oil content in mg/liter must both be based on a common liquid sample volume. The depth of focus and therefore the thickness of the liquid volume photographed has been found to be a function of the drop diameter. To quote the extremes, a 2-micrometer drop is counted in a 9.4-micrometer-thick volume while a 100-micrometer drop is counted in a 127-micrometer-thick volume. Additionally, if a drop is far enough into the photograph for its diameter to be visible, it is counted. This factor is shown diagramatically in Figure 22. The inner rectangle is the actual film aperture and the outer rectangle is the effective liquid volume. It is larger than the film aperture by 1/2 the drop diameter in all dimensions. Equation 2 shows the volume calculation where D is the diameter of the drop.

$$\text{Volume} = (\text{Length} + D)\ (\text{width} + D)\ ((3.86 + (5.09\ \text{Ln}\ D)) + D) \qquad (2)$$

Application of this equation to the measurement range of the system, 2 micrometers to 100 micrometers, indicates that the 2-micrometer drops are counted in a 1.8×10^6 cubic micrometer volume and the 100-micrometer drops in a 36.3×10^6 cubic micrometer volume. If the liquid volume size correction were not made, the calculated oil content would be much higher than actual and the small drops discriminated against in the size dispersion.

Projector, Screen, and Ruler Technique

Manual measurement is the most basic technique and is also the most labor-intensive. The photographic image of a stage micrometer calibration slide is projected upon a screen. The distance between calibration lines is measured and a ratio established between distance measured on the projected image and the known distance between the lines on the stage micrometer. After this calibration, the first of the time-lapse pair is projected and the diameter of all drops and their distance from the corner of the photograph are determined and recorded. The next photograph of the time-lapse pair is projected and similarly measured. The drop diameter and distance moved in a known time are recorded and Stokes law is used to calculate density.

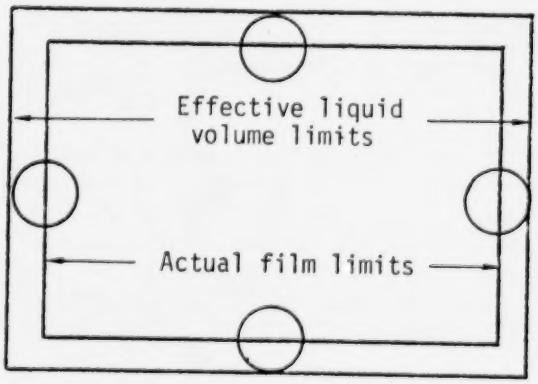

Figure 22. Relation of liquid volume to film aperture.

Digitizer-Computer Technique

The projector and ruler technique is satisfactory when only a few hundred sets of photographs are to be examined. However, when 20,000 photographs are to be examined, as in the case of the offshore use of the system, it becomes cost-effective to develop computer techniques.

A PDP-11 computer was used with a Summagraphics Model HW-2-20 digitizer providing .25 mm resolution. The color photograph is projected upon the platen with a vertical projection system using the modified projector previously described. The primary system calibration was performed by projecting one of the stage micrometer photographs and determining the number of .25-mm digitizer units, called nibbs, required to subtend the known distance. The camera aperture, limit of the projected image, was then measured and used as a convenient secondary standard.

Computer Programs--

The utility of some of the computer programs in this section is immediately obvious. The data reduction programs are the result of the expressed desires of the several people involved in evaluating and reporting of the data. The utility of these programs may be more obscure, but they are included for the sake of completeness. All programs were written by one of the authors, and questions are to be referred to R. A. Meyer.

The programs were developed to run on a DEC PDP11-40 with 128,000 words of memory. The multiple-user operating system, RSX 11M Version 3.2, was in use. Programs were compiled with the ANSI Fortran IV Version 1.8 compiler. The Fortran listing of all programs is included in Appendix B. The top 5 cm of the digitizer platen are reserved for program control action and are referred to as "menu." "I" and "F" refer to the Fortran integer and floating type of numbers.

READ.FTN--READ is a basic photographic image reduction program. It requires a calibration factor of microns in the photographed water/nib (.25 mm) on the platen. Entering Ø for FACTOR results in a factor of 0.01. This converts all diameter data to inches on the platen. The image is touched on its x-sides. The terminal responds with the x-y platen location of both touches, the x-y platen location of the center of the image and the x-width (diameter) of the image in units defined by the FACTOR. Any MENU touch terminates the program. There is no data storage.

SIZE.FTN--SIZE is the primary oil drop photograph processing program. It allows measurement and file storage of up to 600 drop diameters. It is initiated by either the input of the cell-platen factor in micrometers/.01" or Ø. An answer of Ø jumps to a calibration routine where a known distance is requested and entered and the stylus touched to the x-sides of the distance. The overall size of the photographic aperture in the cell has been repeatedly measured as 535 micrometers and is typically used as the known distance. Run number (I2) and film number (I5) are requested by the program and the number of the first frame typed by the terminal. The program expects a digitizer touch on the x-sides of each drop of interest. The terminal types the diameter of the drop and, if it is within .99 to 125 micrometers, increments the table

location equal to the diameter. A MENU touch substituted for the second x-side touch allows the option to terminate by entry of "1234." Any other action returns the program to "measure" and retypes the last frame number.

After each drop in a frame has been processed, a MENU touch is substituted for the first drop side and the terminal types the next frame number. Errors in digitizing are given the preliminary screening by the size and y limits. If a known error passes the screen, it can be corrected by use of ALTSIZ.

Termination of the program closes the output file named SIZEXX.DAT;YY where XX is the operator-defined run number and YY the version. Table location 149 contains the run number; 148 the film number; 147 the number of samples; and 146 the total number of drops. Location 1 contains the number of 1-micrometer-diameter drops found, location 2, the number of 2-micrometer drops, etc., up to 125 micrometers.

ALTSIZ.FTN--ALTSIZ is a program to inspect and/or alter any location in a SIZEXX.Dat;YY file. Locations 1 to 125 of a SIZEXX.DAT file contain the number of drops found whose diameter matches the location, e.g., location 4 = 25 means that 25 drops of 4-micrometer diameter were found in that roll of film. Location 149 contains the run number, 148 the film number, 147 the number of water samples studied, and 146 the total number of drops found.

The program is initiated by specifying a file in the form SIZE.XX.DAT;YY in answer to the question FILE TO ACCESS. The location to be inspected is specified as I3. The terminal types the value stored in that location and offers the option to change by entering (I6), the new number, or CR for no change (zero is a number). A CR response to FILE TO ACCESS or NUMBER TO CHANGE closes the file and terminates the program. The file name and version remain unchanged.

ASIZEPRO.FTN--ASIZEPRO is a program to process the data in a series of up to 10 SIZEXX.DAT (latest version only) files into five forms of output. It is initiated by input of up to 10 (I2) run numbers and their associated oil densities (F12.5). The entry of 0 or CR for FILE TO ACCESS terminates the input, types the identity of the first file on the terminal, and starts processing. When processing of the first file is completed, the identity of the second is typed, and so on.

The first processing step is a DROP NUMBER COMPILATION. The run number, film number, and number of water samples are placed as the sheet header and a three-column output generated of drop diameter in micrometers, number of drops of that size counted, and drops per liter based on the diameter controlled microscope viewing volume. The system has capability of 125-micrometer-diameter drops but the column is terminated when the largest drop is reached. The last output line is the total number of drops and the diameter of the largest one.

The program next generates a histogram that relates average drops per 1000 cubic micrometers to drop diameter in micrometers. It is worthy of note that conversion of number of drops counted to drops per 1000 cubic micrometers can change one drop into many counts in the histogram. The histogram is made

through use of an International Mathematical and Statistical Libraries Inc.* program called USHV1. This program prints a horizontal histogram on one or more pages from a table of data. Copyright restrictions prohibit reproduction of the program. However, assuming that the operator has the program available, the following alterations have been made to expand the dynamic range of the histogram:

USHV1 scales the bar length to fit the longest bar to the page by locating the largest value and dividing by the available space. Thus, one count, a printed I, may equal one or more units. For example, in the data for Run 01, there were 2557 drops counted in 340 water samples and each "I" represented 43 drops. A histogram composed of I's therefore eliminates any knowledge of drop counts less than 21. This severely limits the usability of the data, since over 50% of the total oil is contained in the few large drops that would thus be eliminated. To eliminate the problem, two tests have been added to the IMSL program. If, after the bar height value (T(IJ)) has been divided by AK (the frequency factor), the result is less than 1, T(IJ) is scaled by 10 instead of the frequency factor (AK). If the result is 1 or greater, the line is made from the character "X" rather than"I." If the result is still less than 1, the scale factor is changed to 1 and "0" used to build the line.

This program change results in histogram display of all data. The end print of the histogram displays the frequency and scale values for X and 0; e.g., ONE FREQUENCY UNIT IS EQUAL TO 43 "COUNTS" (UNIT(S)

X= FREQUENCY OF 10 0= FREQUENCY OF 1

The third processing step calculates and prints the mg/L of oil contributed by all the drops of each diameter. The drop weight is calculated as the spherical volume of the drop times its density. The density of the oil is a program input factor. The volume of the water sample photographed is a function of the photographic aperture, microscope magnification, the apparent depth of focus of the optics, and the diameter of the drop.

The size-mg/L table is printed and a histogram made of the data as the fourth section of the output.

The fifth section of the output is a measure of oil dispersion as a function of drop diameter. Starting with the largest drop, the mg/L are successively summed until the value exceeds 25, 50, and 75% of the total oil. The data are printed in the form:

30.8% of the oil was in 1 drops. The smallest diam was 56 u

61.5% of the oil was in 3 drops. The smallest diam was 41 u

76.9% of the oil was in 5 drops. The smallest diam was 33 u

Inspection of the drop number table shows that there was 1-56, 1-46, 1-41, 1-35, and 1-33 micrometer-diameter drops. The printout shows that the sum

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* IMSL, 7500 Bellaire Blvd., Houston, Texas 77036.

of the oil in these five drops was 76.9% of the total oil found at that sample point.

After the fifth output is written into the OIL3.DMP file, the program steps to process the next data file in the input stack. The terminal types the identification data for the file and processing continues. When the last file in the input stack has been processed, the program terminates and the OIL3.DMP file is spooled to the line printer.

SIZMIX.FTN--SIZMIX is used to mix two size files. One example of its use is to gather the data from two runs at a single sample point into a single data file. The two files to be mixed are specified in the SIZEXX.DAT;YY form and only the run number, XX, specified for the output file. Thus one may specify SIZE34.DAT;1 and SIZE34.DAT;3 and 34 as the output file to create SIZE34.DAT;4 from the other two versions. Upon auto-termination of the program the two input files remain unchanged, the new output file is written, and also spooled as RAY.DMP.

SIZMAK.FTN--Most of the data processing programs are directed toward SIZEXX.DAT files. This program addresses a DENS created file, OILXX.DAT;YY, removes the density data and puts the diameter and number of drops data in the format of a SIZE created file, SIZEXX.DAT.

CAP.FTN--CAP is identical to ASIZEPRO with the exception that the run numbers and associated densities of all field test SIZE files have been defined in DATA format. The command RUN CAP causes automatic processing of all presently available oil drop data and the generation of a 3.6-cm-thick printout. The data format may be changed to include any file list by editing and recompiling the program.

ASIZNOR.FTN--ASIZNOR generates data tables from a series of SIZE.DAT files. Up to 10 file numbers (I2)and associated densities (F10.5) may be entered. Entry of 0 as a file number initiates processing. The program opens an OIL3.DMP file, locates and reads the first file and writes in the DMP file a table of diameter vs number of drops found. It then generates and writes (in reverse order) a table of log diameter vs percentage of total drops that are smaller than that diameter. Mg/L of oil are calculated using the algorithm discussed in ASIZEPRO and a table of diameter vs mg/L written into the DMP file. Another reverse order percentage table of mg/L is generated and written and the program repeats until all runs have been processed. The output is spooled to the line printer and the program stops.

CAS.FTN--CAS is the fully automatic version of ASIZNOR and produces the Versetec* plots of the log-normal cumulative probability of percent distribution by number of drops vs size. It also compiles the log size - cumulative % data into an OIL3.DMP file. The spool command is "commented out."

CAM.FTN--CAM is identical to CAS but the data base is calculated to cumulative mg/L oil. Calculation of oil content is identical to that in ASIZEPRO and CAP.

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* Versetec, 2805 Bowers Ave., Santa Clara, California 95051.

DENS.FTN--DENS is used to determine the diameter and x-y position of the same drop in a pair of time-lapse photographs and calculate its density. It creates a 1200-word file called OILXX.DAT for storage of data. The odd-numbered locations hold the Fortran "real" diameter of a drop and the next even location holds its associated density (real).

A calibration action initiates the program. The program prompts "CALIBRATION: ENTER MICRONS AND TOUCH 2 LINES* MICRONS BETWEEN LINES IS." The operator selects a known distance, typically the x sides of the image, and enters the known distance, typically 535 microns. He then touches the stylus to each side in turn. The program returns a factor in micrometers in the microscope cell per nib (digitizer increment). Then, following program prompting, the program is continued by input of run number (I2), film number (I3), water density (F12.6) and water viscosity in stokes (F12.6). The program prompts with a number representing the first diameter storage location. Without further prompting, it expects a digitizer value (touch) for the lower left corner of the first photo frame and the 2-x sides of the drop.

Diameter and x-y location are printed. If the diameter is less than 0.1 or greater than 200 micrometers, the operator is notified and the number rejected. Similar rejection occurs if the y positions of the drop side locations are more than 2.5 mm apart. Without further prompting, similar digitizer positions are expected for the second photo frame in the time-lapse series. The size and location of the drop in the second photo are printed and a number indicating the time interval between photos is requested. The program calculates and prints average diameter, difference between diameters in the two photographs, density, x movement between photos (rise or fall of drop) and y (side) movement between photos. A carriage return enters the data in the file and resets for the next drop pair. Any number followed by a carriage return discards the data and returns for the next drop. A touch in the upper 2 inches of the digitizer tablet instead of the lower left photo corner allows the option to end by entering 123. Any other number returns to the next drop pair. The 123 entry places the number of drops in location 600, run number in 599, film number in 598, water density in 597, and the water viscosity in 596. It writes the file and closes it. All numbers are real.

The data in the OILXX.DAT file is processed by DENSPR or SIZMAK and inspected or changed by ALTDEN.

ALTDEN.FTN--ALTDEN addresses any OILXX.DAT;YY file and permits the inspection or change of the value stored in any location. Note that subsequent programs inspect the diameter locations searching for a 0 value which indicates termination of data. Elimination of a value by changing it to zero may cause trouble in the future. The program is run similar to ALTSIZ.

DENSPR.FTN--DENSPR processes the (1,1200) files created by DENS. It is initiated by input of the file to process in the OILXX.DAT;YY form. Without further user action, the program creates an OIL.DMP file and spools it to the line printer. The printout consists of a run data header followed by, for each integral drop diameter, the total number of drops of that diameter that were found and their individual densities. The program auto-terminates.

GRAPH.FTN, PGBR.FTN--These programs were written by another programmer to generate plots of log-normal probability data on a Veraplot-07 made by Versetec.* They are included for completeness and are used in programs CAS and CAM. The techniques used should be easily understood by a competent programmer.

Non-Fortran Subroutines--

Tab

Call Tab (NX, NY, MENU). This subroutine interfaces with the Summagraphics digitizer platen. When the stylus is touched to the platen, the subroutine returns the x, y coordinates in integer nibs. There are 33.37 nibs per cm. The upper 6.25 cm are reserved and called MENU. This area is usable for program control. Thus the Fortran programs expect either two I4 numbers representing x-y location, or a number representing MENU.

Fils

Call Fils (File, 'prefix,', NN, 'ext')

Fils is a subroutine to generate an ASCII string for a filename of form:

PPPPPPXX.ext

where

PPPPPP = a prefix string of any length

XX = a two-digit decimal number

ext = 3 character extension string

The resultant filename string is terminated by a null byte and thus is acceptable to the "assign" library routine. It is stored in the array defined by the "file" input.

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* Versetec, 2805 Bowers Ave., Santa Clara, California 95051.

SECTION 6

OPERATING INSTRUCTIONS

These operating instructions are specifically directed toward use of the system for the determination of oil drop size distribution in treated, produced oilfield brine. While there are only very broad limitations on the application of this system to other problems, detailed general instructions are well beyond the scope of this development. The user is cautioned that the changing physical requirements dictated by different samples may require significant alteration of the operation instructions. Even within the sample type addressed in this work, changes in operating parameters can greatly alter the drop size and density cutoff points. The effect of changes in pertinent instructions will be discussed, along with the specific instructions.

SAMPLE REQUIREMENTS

Sample has typically been conducted to the system in a short, 16-mm (5/8-inch-) -diameter garden hose. The entrance to the Teflon standpipe block is female 12.7-mm (1/2-inch) standard pipe thread and any desired fitting may be installed. Sample pressure must be at least 22 cm of water, but should be between 40 and 100 cm. The system has been tested to a sample pressure of 460 cm of water with a 9.5-mm-ID by 30.5-cm-long transfer line without overflow of the standpipe. Higher sample pressures would overflow the collection tube of the standpipe and slightly increase the cell pressure. This would not be expected to influence the system operation except to provide an excess sample disposal problem.

Each 4-second cell flush period requires 138 ml. If the system is used in the single-photograph mode, the cell flow is 1700 ml/min. In the three-photo-triad mode, the cell flow is 700 ml/min. These values establish the absolute minimum sample requirements. If the cell is flushed continuously, the sample throughput is 2075 ml/min. This should be considered a minimum flow since, during the flow static periods, the excess sample would overflow the standpipe and establish the desired bypass sample condition. This condition assures that fresh sample, uniformly dispersed by turbulent flow, is always present at the cell entrance. Maximum flow is dictated by standpipe overflow disposal capabilities.

Pipeline sample point location and valve type are seldom user-controllable parameters. Isokinetic sample withdrawal from the center of the flowing stream would be ideal but, in most cases, both difficult to achieve and unnecessary. Very good results were obtained by installing a bored-through Swagelok 810-1-8, 1/2-inch tube to 1/2-inch pipe male connector, fitted with Teflon ferrules

in the outlet of a 1/2-inch gate valve. (English units are used to refer to standard fitting sizes.) The sample withdrawal tube was 1/2-inch-OD, thin-walled stainless tube with one end closed and a 3/8-inch hole in the side very close to the closed end. The tube, which was long enough to reach the center of the pipeline, was pushed in to the face of the closed valve gate, the tube fitting gently tightened, the valve opened and the tube slid through the Teflon ferrules until the side opening was looking upstream and in the center of the pipe. The tube fitting was tightened just enough to prevent leakage, and sampling progressed.

During the field work, sample outlets ranged from the above desirable configuration to a completely undesirable 1/4-inch needle valve in the side of a vertical pipe. In any case, the valve MUST NOT BE USED TO CONTROL FLOW. The sample must not be subjected to the shear caused by rapid flow through a small orifice or the drop size dispersion will be altered. Sample transfer lines should be at least 9.5 mm ID and as short as practical. Excess sample (standpipe overflow) should be disposed of in a manner consistent with the nature of the sample. The disposal tube must be large enough to carry the flow without generating backpressure, which would cause the standpipe overflow collection tube to overflow.

CASE PREPARATION

Microscope Focusing and Calibration

The system is designed for use in NEC Class 1, Division 1, Group D known explosive atmospheres. Since there are no provisions for focusing from the outside of the pressurized case, the focusing and calibration must be performed in a safe area. An electrical jumper plug is provided on the side of the lower case section to defeat the case pressure safety switch. (The upper section cannot be installed with this jumper in place.) Assure that the surrounding area is safe (nonexplosive atmosphere) and connect the jumper. Depression of the FOCUS pushbutton (Figure 23) should now cause the strobe to flash at a rate of 75 Hz, which the eye sees as continuous illumination.

Flash Tube Adjustment

The illumination source consists of a flash tube mounted in a reflector. The power supply is remotely located within the case. The angle of the light source is controlled by adjustment of three spring-loaded screws in much the same manner as that of an automobile headlight. The other focusing variable is the position of the substage condenser. It should be re-emphasized that the physical constraints of the system preclude estabishment of Koehler illumination. The following adjustments should be performed in very subdued light. It is also advantageous to shield the eye from stray strobe flash light by draping the system with black cloth.

Remove the camera back and place a sheet of tissue over the film aperture. While making individual exposures with the camera switch on the outside of the housing, adjust the three screws to achieve even lighting over the focal plane. Adjust the substage condenser to eliminate any "hot" spots or shadow bars. The adjustments interact and the cycle should be repeated until maximum

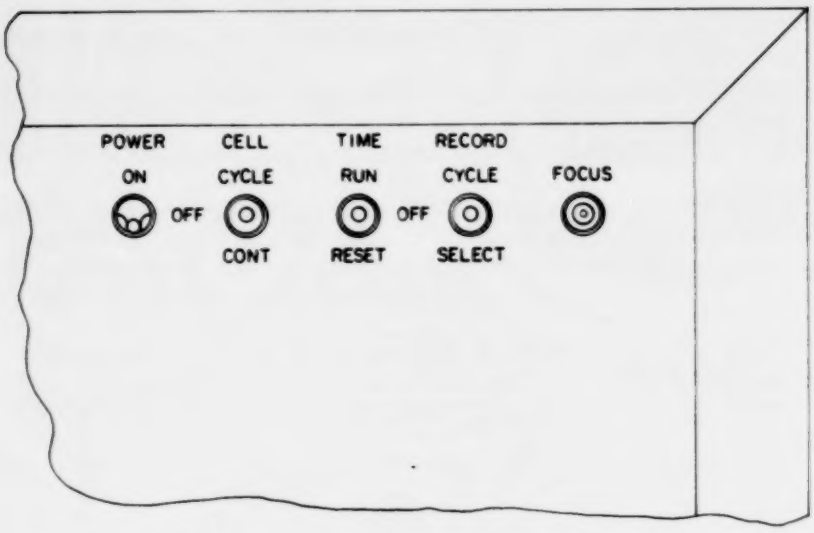

Figure 23. External switches.

even illumination is achieved. A photoelectric measurement system was tested during development and two operators achieved almost identical results with the unaided eye. This adjustment proved stable during field operation and is suggested as an initial setup step.

Calibration

Calibration is normally done in the laboratory, but if the objective, photo eyepiece or tube length are changed, can be performed in the field. The following stepwise procedure should be followed:

(a) Load the camera. Typically, a 20-exposure cartridge of Tri X black and white film is used.

(b) Orient the system with the microscope axis vertical.

(c) Attach the Varimagni finder.

(d) Assure that the beam splitter knob is out and the safety jumper plug is connected.

(e) Place the stage micrometer slide on top of the cell with the graduated section up and centered in the field.

(f) Depress the FOCUS switch and focus the image. Note that the stage, not the microscope, moves. This results in a reverse action of the focusing knob.

(g) Re-center the calibration scale in the field of view with the scale running across the wide axis of the image. Crude calibration may

now be made by counting the lines in the field. They are 10 micrometers apart.

(h) Release the illumination switch and actuate the RECORD switch, Figure 23, to the select side several times. Each actuation should open the shutter, flash the strobe, and advance the film.

(i) Process the film in Eastman HC110 developer Dilution B for 10 minutes at 20°C. Fix and wash. The processing may be altered to suit the desires of the operator. High-contrast processing for an ASA rating of 800 to 1600 is required.

These negatives are used to establish the magnification ratio between the object and the projected image during digitization. The lines on the scale are 10 micrometers apart. Any other stage micrometer may be used based on the magnification.

Focusing

Focusing, like calibration, is a safe-area operation. The following operations successively establish the focal plane at the outer cell wall face, the inner cell wall face and, finally, the desired 600 micrometers into the liquid volume. Please refer to Figure 24, steps 1 through 4. The point of the arrow indicates the focal point.

(a) Perform Steps b, c, and d of the calibration operation.

(b) Place a thin, transparent sheet of paper such as a single Kimwipe or sheet of toilet tissue on the top of the cell.

(c) Depressing the FOCUS switch, focus upon the paper (step 1).

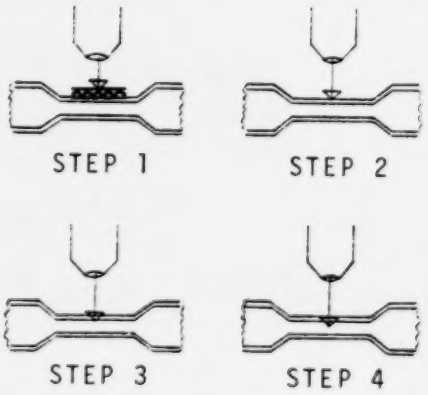

Figure 24. Focusing operations.

(d) Remove the paper and shorten the focal distance (turn the focusing knob clockwise) to bring the top surface of the cell into focus (Step 2).

(e) Loosen the stage attachment dovetail screws and slide the cell toward the microscope column until the cell wall is visible in the image. Adjust the cell position so the center of the image is a nominal 1 mm inside the cell wall and tighten the screws.

(f) Again establish the focal plane on the upper cell face and shorten the focal distance until the focal plane is at the inner face of the upper cell wall. Since the cell wall is 1.6 mm thick, this should require eight revolutions of the fine focusing knob (Step 3). Turn the fine focusing knob an additional 3 revolutions clockwise to establish the focal plane 600 microns into the liquid volume (Step 4).

Focusing is now complete. The horizontal cell position seldom moves even in shipping, but it should be checked after each transport of the system. Focus also is typically stable but must be verified after transport. Practice has shown that focus does not change during movement to several sampling points on a platform and it has seldom shown a change after shipment.

The positioning of the viewing zone 1 mm from the top of the liquid cell (when the optical axis is horizontal) was chosen to optimize the system for oil drops that are lighter than water. This position also establishes a maximum discrimination against objects that are heavier than water. To study heavy objects, the viewing zone should be closed to the bottom. Optimum zone position can be calculated by application of Stokes' law.

An optional but less desirable focusing technique is to place a suitable spacer between the outer cell wall and the microscope objective and, very slowly and carefully, bring the objective into contact with the spacer. The spacer thickness is a function of the cell wall thickness.

CAMERA AND FILM PREPARATION

After the photomicrographic system has been focused, the camera may be removed and replaced at will without compromising the focus. Follow the manufacturer's instructions for lens removal and replacement, substituting the words "Microscope system" for "lens." Attach the camera back consistent with the desired film length.

Loading 250-Exposure Magazines

Study the manufacturer's magazine loading instructions with care before continuing with the reading of this section. The following discussion presents one satisfactory way of implementing these instructions under field conditions. Olympus supplies an expensive magazine loader that has to be used in a darkroom and seemed to offer little advantage for field work. A cartridge-type bulk

film daylight loader such as the Watson Model 100* could be modified to perform the loading operation in the daylight. However, for budgetary considerations, the following technique was used.

All film loading operations are performed in a photographic changing bag. This is a double-walled, dual-zipper closed bag of opaque fabric. There are two elastic belted arm sleeves attached to the bag. It is recommended that a 100-foot roll of film be loaded into three magazines during one operation. Accordingly, place three complete magazines, a film can holding 100 feet of film, a pair of sharp scissors, the film spool holder, the magazine spool rotation stick, and a roll of masking tape into the inner bag and close both zippers. The masking tape is not normally used, but is desirable for unplanned reclosure of a partly emptied film can.

Insert the arms into the sleeves with the elastic belt above the elbows, open the can, remove the film (save the plastic bag for reuse), remove the small piece of tape from the film roll, place the film spool over the upright tube of the film spool pedestal, cut the film end and load the three magazines following the manufacturer's instructions. Eighty-four revolutions of the magazine spool place 33 feet of Ektachrome film on the spool. This is a factor of the film base thickness. Use care when cutting the film ends so as not to cut either the bag or the fingers, and note that both are very easy to accomplish. Since practice promotes perfection, it is recommended that the operations be performed in the light with test film and also repeated without observing the action (eyes closed).

Camera Loading

Loading of 20- and 36-exposure film cartridges into the camera and loading of 250-exposure magazines are described in the manufacturer's instructions. A note of caution is worthwhile here. If the film end is not SECURELY attached to the takeup spool or if the small knurled fork knob is not completely engaged, the film will advance for about 20 exposures and jam. The practice of placing a small piece of masking tape over the film-spool joint after the reverse bent tongue is put in the spool slot is highly recommended. As noted earlier, film sticking due to high humidity precluded camera operation during one phase of the field work. The problem was eliminated by filling the magazines and loading the camera in an air-conditioned area. The loaded camera was transported to the filming site in a closed plastic bag.

Film Coding

The film should be coded by punching small (1/4-inch-diameter or less) holes in the center of the film. Film was coded o ooo to indicate platform 1, Run 3. Care must be exercised to keep the holes small and well inside the sprocket holes.

SAMPLE POINT CONNECTION

Sample points and their connection to the PMS were discussed earlier. No

* Pfefer Products, Simi Valley, California.

definitive instructions can be given due to the wide variation in available connections and pressures. The basic requirements are an absolute minimum flowrate of 2000 cc/min. and a desirable range of 5 to 10 liters/min. Low pipeline pressures on some platforms required establishment of the PMS on a lower sub-deck to achieve the desired flow. Lack of a sampling port on one platform dictated a syphon system to remove the sample. Thus the connection to sample source must remain the province of the operator. Sample flow may never be modulated with a valve. Sample excess and used standpipe overflow must be disposed of in a manner consistent with sample composition and minimum flow requirements must be met.

MAKING THE RUN

1. Assure that the loaded camera is ready for use:

    . Rewind knobs engaged

    . Exposure counter set

    . Motor drive in single mode

    Plug the mini-phoneplug into its socket on the top of the motor drive and connect the flash connection at the top of the camera. Set the camera shutter speed at 1/30 second.

2. Select the desired photographic mode (photo triad or single shot) and adjust the selection switch on the electronic box accordingly.

3. Attach the plastic housing top and latch all fasteners. Establish sample flow to overflow the standpipe.

4. With reference to the rubber boot sealed switches on the side of the PMS, Figure 23:

    . Turn all switches off. Note that all are double throw - center-off switches.

5. Turn pressurization gas source on and assure that the regulator is set to 10 inches of water pressure (2.5 kPa).

    Turn the power switch on and turn the cell switch to continuous. This should result in an audible "thump" as the valve actuates and also sample flow at the sample exhaust port.

    Turn the time switch to reset, then to the run position.

    After 120 seconds, turn the cell switch to the cycle position. The valve should now cycle either 4 seconds on and 12 seconds off, or 4 seconds on and 1 second off, depending upon the selected photographic cycle.

After 60 seconds of correct operation, turn the record switch to CYCLE. The run is now started and should proceed without further interaction until the film is exhausted.

The proper progression of the run should be monitored by observing the following actions:

Continuous sample overflow at the standpipe

Four-second pulses of sample flow from the sample exit port

Film advance which is indicated by regular progression of the exposure counter from 250 toward zero

As the exposure counter nears zero, it may stop advancing. This typically indicates exhaustion of the film supply. The camera automatically stops advancing when the counter reaches zero. Should film advance stop during the run, the operator should check for low battery voltage by observing sample flow and monitoring the solenoid valve operation "thump." Lack of either indicates low system battery voltage.

Assuming that valve operation is normal, the most likely cause of malfunction is the film transport. The operator may either terminate the run or attempt to remedy the cause of the malfunction. In either case, the following housing depressurizing sequence must be followed:

- Turn all switches off.
- Turn pressurization gas source off.
- Open case by opening latches and remove the plastic top section.

The operator may now remove the entire camera to the changing bag, open the back and try to ascertain and remedy the cause of the malfunction by feel. Some failures are obvious to the touch. Film folded between the takeup magazine and the camera film advance sprocket indicate film detachment from the takeup spool, non-engagement of the knurled takeup knob or attempted operation with the takeup magazine closed. Some failures may be remedied in the changing bag without loss of exposed film. The operator must weigh the value of the exposed film against the value of the remaining film. It is also possible to close both magazines, cut the film and save both the exposed and unexposed film at the possible complication of the processing step.

When the run has proceeded to completion, follow the depressurization instructions, remove the plastic housing top, close both magazines, open the camera back, and remove the film magazine.

After the film in three magazines has been exposed, place the three magazines, an empty 100-foot film can, the plastic bag that originally held the film, and a roll of masking tape into the changing bag and close both zippers. Insert the arms, open the magazines in turn and wind the three rolls of film into a single roll. Place the roll in the plastic bag and into the film can.

Tape the lid of the can to the lower part with masking tape. The tape eliminates the remote possibility of stray light penetration and insures that the top is not removed unintentionally. The film can should be marked. LOOSE EXPOSED FILM. OPEN ONLY IN DARKROOM. Details of film processing are left to the operator. Please refer to Section 5 for a discussion on film selection and processing.

HIGH OIL SAMPLES

The photomicrographic system was designed for use with flowing streams of processed brine samples having oil contents ranging from 10 to 1000 mg/L. Higher oil content samples exist in the production system and a pre-separation technique has been developed to study the 1- to 100-micron-diameter drops in these samples. A preliminary separation is made in the sampling device diagrammed in Figure 25. The 6-liter cylinder is filled from the bottom with all valves open to minimize shear. After at least 30 liters have passed through the cylinder, the valves are closed in anti-flow direction sequence starting at the flow control valve. Again, this minimizes valve-induced shear since the liquid is stationary when the lower sample valve is closed. Pressure is released at the cylinder top valve and, after allowing separation time, the water phase is passed through the photomicrographic system at the normal rate.

Sample volume is limited by the capacity of the separator and the water-oil ratio. To obtain the maximum number of photomicrographic samples, the overflowing standpipe feature is eliminated. The standpipe is removed and replaced with a solid plug (Figure 9). Thus, all the water in the separator is available for use as cell flush and sample. The water level in the separator must be maintained at least 22 cm above the cell to furnish hydrostatic head to ensure the normal 138-ml-per-flush flow. Connection line length is kept at a minimum to ensure that the 138-ml flush volume delivers sample fresh from the separator to the cell. The separation time, sample withdrawal rate, and fluid parameters combined to fix a maximum possible drop size.

The upper drop size limit is caused by the interaction of the rise rate of the drops in the high oil sampler and the rate at which the liquid level falls during sample withdrawal.

Equation 3 relates the fluid parameters and relevant times through Stokes equation to the upper drop size limit in the sample.

$$D = \left(\frac{[1 + aT_2]\ 18h}{60\ g\ (D_{brine} - D_{oil})\ (T_1 + T_2)} \right)^2 \qquad (3)$$

a = cm/min drop in reservoir level (11.6 for triad sets, 37 for single shot)

D = upper drop diameter limit (micrometers)

D_{brine} = density of brine

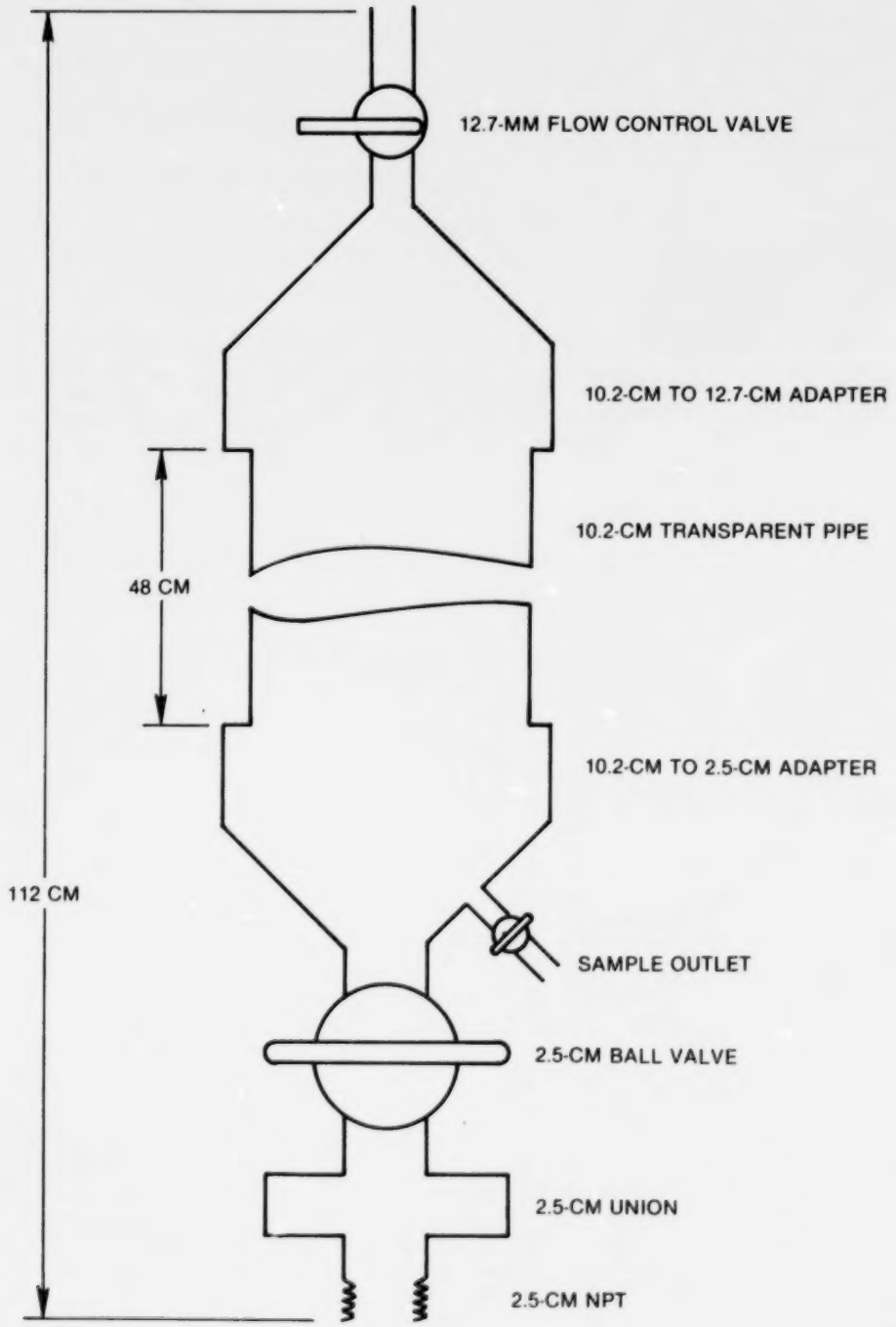

Figure 25. High oil sampler.

D_{oil} = density of oil

g = 980

T_1 = static period (min)

T_2 = time after start of sampling (min)

Figure 26 shows application of Equation 3 to typical Phase 2 fluid parameters. The difference between the triad and single-shot curves is due to the much higher sample consumption rate during single-shot photography.

This technique may be applied to any grab sample system. The user is cautioned that great care must be exercised that sample alteration does not negate the results. Factors such as matrix-particle density difference, settling time, and sample withdrawal rate will all affect the particle size cutoff point and must be well evaluated.

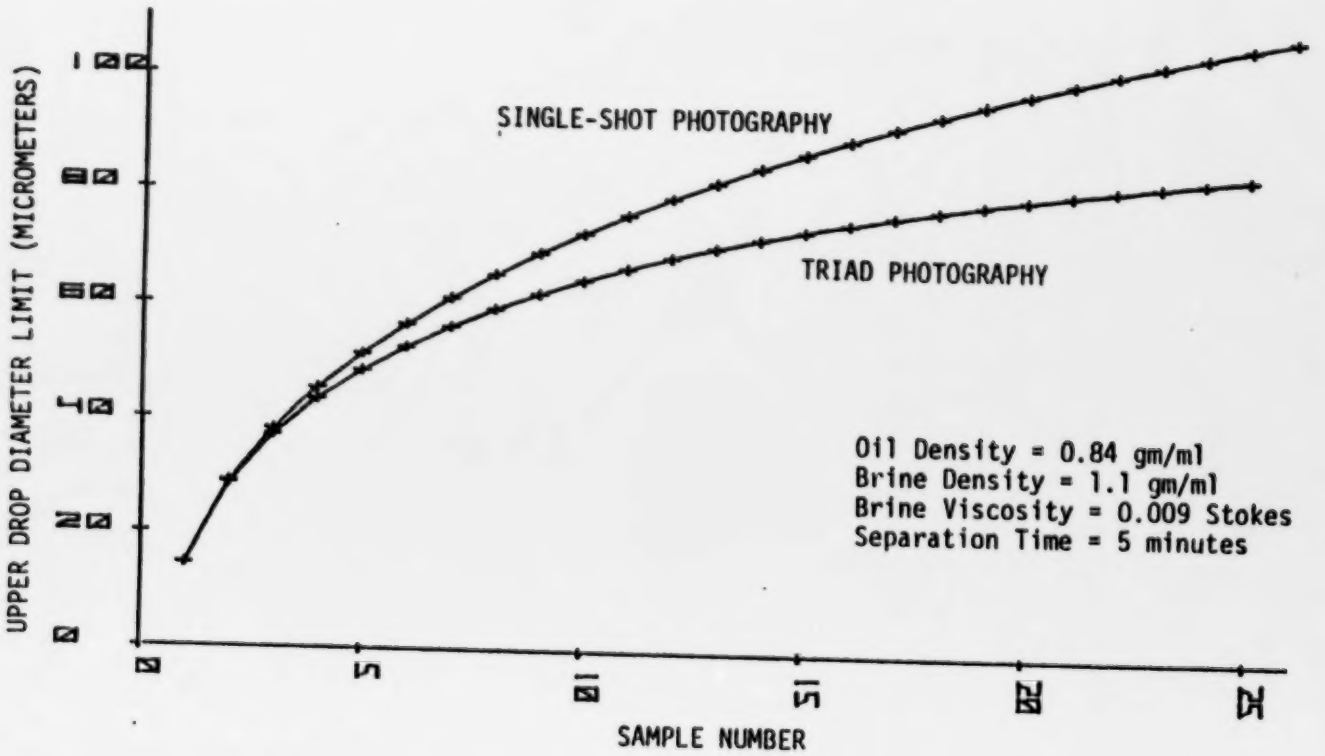

Figure 26. High oil sampler upper drop diameter limits.

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2. Karabelas, A.J. Recent Studies Improve Velocity Criteria Used for BS&W Sampling. The Oil and Gas Journal. pp.98-104. April 17, 1978.

3. Karabelas, A.J. Droplet Size Spectra Generated in Turbulent Pipe Flow of Dilute Liquid/Liquid Dispersions. AIChE Journal, Vol. 24, No. 2. pp. 170-180. March 1978.

APPENDIX A

VISCOSITY ESTIMATION

The U.S. Department of Interior Office of Saline Water R&D progress report 363 contains data on viscosities of saline solutions at several temperatures. Table A-1 presents a portion of their data. Within each temperature the density-viscosity data fit a parabolic model.

$$\text{Viscosity at } 25°C = 9.2016 - (17.4351 \text{ density}) + (9.1308 \text{ density}^2)$$

$$\text{Viscosity at } 40°C = 5.3765 - (10.3764 \text{ density}) + (5.6665 \text{ density}^2)$$

$$\text{Viscosity at } 60°C = 2.9555 - (5.8677 \text{ density}) + (3.4026 \text{ density}^2)$$

Viscosity is calculated for the two temperatures that bracket the sample temperature and interpolated in a linear fashion to the sample temperature. This leads to the estimation for viscosity in Table 1, page 10, for the produced water on three of the platforms investigated. It is assumed that cell temperature stabilizes near sample temperature.

TABLE A-1. MEASURED VISCOSITIES AND DENSITIES OF BINARY AQUEOUS NaCL SOLUTIONS

Temp., °C	Molality	Density	ν (cs)	η_R Exp.	η_R Calc.
25	0.0999	1.0011	0.8980	1.010	1.009
	0.7069	1.0253	0.9243	1.065	1.065
	1.4138	1.0514	0.9636	1.138	1.140
	3.5345	1.1226	1.1358	1.432	1.431
40	0.0999	0.9961	0.6627	1.011	1.010
	0.7069	1.0197	0.6880	1.075	1.074
	1.4138	1.0453	0.7212	1.155	1.154
	3.5345	1.1154	0.8524	1.457	1.456
60	0.0999	0.9871	0.4786	1.013	1.012
	0.7069	1.0104	0.5009	1.085	1.084
	1.4138	1.0356	0.5277	1.171	1.170
	3.5345	1.1047	0.6258	1.482	1.482
75	0.1001	0.9786	0.3920	1.014	1.013
	0.7083	1.0016	0.4118	1.090	1.090
	1.4166	1.0272	0.4352	1.181	1.181
	3.5408	1.0969	0.5170	1.499	1.500
100	0.1004	0.9623	0.2981	1.017	1.014
	0.7103	0.9855	0.3143	1.098	1.099
	1.4207	1.0113	0.3333	1.195	1.195
	3.5502	1.0813	0.3976	1.525	1.526
125	0.1009	0.9434	0.2396	1.019	1.015
	0.7144	0.9671	0.2535	1.105	1.106
	1.4289	0.9935	0.2695	1.207	1.208
	3.5686	1.0644	0.3225	1.547	1.550
150	0.1020	0.9221	0.2015	1.024	1.017
	0.7217	0.9466	0.2134	1.113	1.113
	1.4438	0.9738	0.2273	1.220	1.220
	3.6024	1.0469	0.2724	1.571	1.573

S.D. = 0.17%

ν Kinematic Viscosity (centistokes);
Molality (g moles salt/1000 g H_2O);

$\eta_R = \frac{\eta_{soln}}{\eta_{H_2O}}$; Density (g/cc).

APPENDIX B

FORTRAN PROGRAMS

This is a complete compilation of all Fortran data reduction programs used to measure oil drop size dispersion from a series of photomicrographs. The use of the programs is covered in the body of the report.

READ.FTN

```
C     THIS PROGRAM REQUIRES A FACTOR IN
C     MICROMETERS PER .01 INCH OR IT WILL
C     SET THE FACTOR TO .01 AND READ IN
C     INCHES ON THE PLATEN.  AFTER THE
C     FACTOR IS INPUT A TOUCH ON ONE SIDE
C     RETURNS THE X-Y LOCATION.  A TOUCH
C     ON THE OTHER SIDE RETURNS THE SECOND
C     X-Y, THEN THE DELTA X AND Y IN .01 INCH
C     FOLLOWED BY THE SIZE IN MICROMETERS.
C     MENU EXITS THE PROGRAM.
C
C
      TYPE 1
1     FORMAT('$FACTOR?')
      ACCEPT 2,F
      IF (F.EQ.0.) GO TO 20
2     FORMAT(F10.3)
556   CALL TAB(NX1,NY1,MENU)
      IF (MENU)STOP
      TYPE 25,NX1,NY1
      CALL TAB(NX2,NY2,MENU)
6     FORMAT(I5)
      IF(MENU)STOP
      TYPE 25,NX2,NY2
      IDX=IABS(NX1-NX2)
      IDY=IABS(NY1-NY2)
      TYPE 25,IDX,IDY
25    FORMAT(2I10)
      ID=MAXO(IDX,IDY)
      VAL=F*ID
      TYPE3,VAL
3     FORMAT(X,F6.1)
      GO TO 556
20    F=.01
      GO TO 556
      END
```

SIZE.FTN

```
C          SIZE IS A PROGRAM TO PERMIT MEASURMENT OF THE
C     SIZES OF PROJECTED IMAGES AND STORE THEM IN A FILE
C     CALLED SIZEXX.DAT;YY.  DIAMETERS GREATER THAN 125
C     OR LESS THAN 0.99 MICROMETERS ARE REJECTED.  DATA
C     ARE IN 150 LOCATIONS WHOSE NUMBER IS EQUIVALENT TO
```

```
C     THE DIAMETER AND THE VALUE, THE NUMBER OF DROPS
C     FOUND.  A MENU TOUCH PERMITS TERMINATION.
      BYTE FNAME(20)
      DIMENSION I(150)
4     FORMAT('$ F12.6 FACTOR IN MICRONS PER HUNDRETH INCH IS 0=CAL')
75    FORMAT(3F10.1)
      TYPE 4
      ACCEPT 5,F
      IF(F.EQ.0) GO TO 500
2     FORMAT('$ I2 RUN NUMBER IS  ')
502   TYPE 2
      NUD=0
      ACCEPT 3,IR
      TYPE 19
19    FORMAT ( '$ I3 FILM NUMBER IS   ')
      ACCEPT 3, IFM
3     FORMAT(I5)
      CALL FILS(FNAME,'SIZE',IR,'DAT')

      CALL ASSIGN(2,FNAME)
      DEFINE FILE 2(1,150,U,IV)
      NS=1
      DO 600 MM=1,150
      I(MM)=0
600   CONTINUE
5     FORMAT(F12.6)
      WRITE (2'1)I
      CALL CLOSE (2)
      CALL ASSIGN(2,FNAME)
      DEFINE FILE 2(1,150,U,IV)
      READ (2'1)ID
255   TYPE 3,NS
111   CALL TAB(NX1,NY1,MENU)
      IF(MENU) GO TO 900
      CALL TAB (NX2,NY2,MENU)
      IF(MENU) GO TO 905
      NY=IABS(NY1-NY2)
      IF(NY.GT.10) GO TO 915
      DT=(IABS(NX1-NX2))*F
      TYPE 75,DT
      IF (DT.LT..99.OR.DT.GT.125.) GO TO 907
      IDT=INT(DT+.5)
      DO 102 N=1,145
      IF (IDT.EQ.N)GO TO 105
102   CONTINUE
105   I(N)=I(N)+1
      WRITE(2'1)I
      NUD=NUD+1
      GOTO 111
916   FORMAT( ' Y IS OUT OF LIMITS ',F12.1)
```

```
915  TYPE 916,(NY*F)
     GO TO 111
907  TYPE 908
908  FORMAT( ' OUT OF LIMITS')
     GO TO 111
500  TYPE 20
20   FORMAT('  CALIBRATION:ENTER MICRONS;TOUCH TWO LINES')
21   FORMAT('$ I5 MICRONS BETWEEN LINES IS   ')
     TYPE 21
     ACCEPT 3,IM
     CALL TAB(NX1,NY1,MENU)
     IF(MENU)GO TO 400
     CALL TAB(NX2,NY2,MENU)
     IF(MENU) GO TO 400
     IDX=IABS(NX1-NX2)
     IDY=IABS(NY1-NY2)
     IDT=MAXO(IDX,IDY)
     FIM=FLOAT(IM)
     F=FIM/IDT
25   FORMAT('  FACTOR IS  ',F12.6)
     TYPE 25,F
     GO TO 502
900  NS=NS+1
     GO TO 255
905  TYPE 100
100  FORMAT( '$ TO END TYPE 123')
     ACCEPT 3,ITST
     IF(ITST.EQ.123) GO TO 400
     GO TO 255
400  I(149)=IR
     I(148)=IFM
     I(147)=NS-1
     I(146)=NUD
     WRITE (2'1)I
     CALL CLOSE(2)
150  FORMAT(2I5)
     END
```

ALTSIZE.FTN

```
C         ALTSIZ IS A PROGRAM TO SEE AND ALTER
C    IF DESIRED THE NUMBER IN ANY LOCATION OF A
C    SIZE CREATED FILE.  INDICATE THE DESIRED FILE
C    BY  SIZEXX.DAT;YY. CHANGE LOCATION=0
C    TERMINATES THE RUN.
C
C
     DIMENSION I(150)
```

```
      BYTE FNAME(20)
21    TYPE 4
4     FORMAT('$ FILE TO ACCESS IS  ')
      ACCEPT 5, N, FNAME
10    FORMAT(50I2)
5     FORMAT(Q,20A1)
      IF (N.EQ.0) STOP
      CALL ASSIGN (3, FNAME,N)
      DEFINE FILE 3(1,150,U,IV)
      READ(3'1)I
      TYPE 200,I(149),I(148),I(147),I(146)
200   FORMAT( '  RUN ',I5,' FILM ',I5,' SAMPLES ',I5,' DROPS ',I5)
100   TYPE 103
102   FORMAT(Q,I5)
103   FORMAT( '$ NUMBER TO CHANGE IS   ')
      ACCEPT 102,NQ,NN
      IF(NN.EQ.0) GO TO 20
      READ (3'1)I
      TYPE 104,I(NN)
104   FORMAT( ' IS ',I6,' CHANGE TO ? CR=NO CHANGE')
      ACCEPT 102,NQ,IDT
      IF(NQ.EQ.0) GO TO 100
      I(NN)=IDT
      WRITE (3'1)I
      GO TO 100
20    CALL CLOSE (3)
      END
```

ASIZEPRO.FTN

```
C       ASIZEPRO IS A PROGRAM TO AUTOMATICALLY PROCESS
C     A GROUP OF FILES CREATED BY SIZE.  IT REQUESTS
C     THE RUN NUMBER (I2) AND THE ASSOCIATED OIL
C     DENSITY FOLLOWED BY THE NEXT FILE DESIRED UP TO
C     A LIMIT OF 10.  ENTRY OF 0 FOR THE FILE NUMBER
C     CAUSES AUTO PROCESSING OF THE DESIRED FILES.
C     IT CREATS AND SPOOLS AN OIL3.DMP FILE CONTAININ
C     THE DROP NUMBER AND MG/L COMPILATIONS AND ALSO
C     THE HISTOGRAMS OF BOTH.  FINAL PRINT IS THE
C     SMALLEST DROP DIAMETER TO CONTAIN 25,50,75
C     PERCENT OF THE TOTAL OIL.
C
C
C
      BYTE FNAME(20)
      DOUBLE PRECISION SIZE
      DIMENSION D(10),A(132),IW(132),W(132),IR(10)
             DIMENSION ID(150),RI(150),RD(150),IOPT(5)
```

```
      DATA IOPT / 0,1,500,1,0 /
      DATA SIZE / 'SIZE    ' /
    4 FORMAT('$ FILE TO ACCESS IS  ')
    3 FORMAT(I5)
      DO 500 LS=1,10
      TYPE 4
      ACCEPT 3,IR(LS)
      IF (IR(LS).EQ.0)  GO TO 501
      TYPE 121
      ACCEPT 22,D(LS)
  500       CONTINUE
   10       FORMAT(50I2)
    5 FORMAT(Q,20A1)
  501       CALL ASSIGN (8,'LS:OIL3.DMP')
      LS=LS-1
      DO 502 LB=1,LS
      CALL FILS(FNAME,'SIZE',IR(LB),'DAT')
      WRITE (5,550) FNAME
  550       FORMAT(X,20A1)
      CALL ASSIGN (3, FNAME)
      DEFINE FILE 3(1,150,U,IV)
  600       READ (3'1)ID
      SPPM=0
      NUD=0
   12       FORMAT(' RUN NUMBER ', I5,I7,' WATER SAMPLES
     2 FILM ',I4)
  121       FORMAT(  '  OIL DENSITY F12.5= ')
   22       FORMAT(F12.5)
      DEN=D(LB)
      KKS=ID(149)
      KS=ID(147)
      KFM=ID(148)
      TYPE 12,KKS,KS,KFM
      NS=ID(147)
      WRITE (8,105)KKS,KFM,KS
105  FORMAT ( ' RUN ',I5,'  FILM ', I5,' WITH ',I5,' SAMPLES')
     WRITE(8,301)
301  FORMAT( '  DROP NUMBER COMPILATION')
     DO 151 M=1,145
     IF(ID(M).NE.0)MS=M
151  CONTINUE
     WRITE(8,25)
25   FORMAT ( '  SIZE NUMBER  DROPS PER LITER')
     DO 120 M=1,MS
     DIA=FLOAT(M)
     DP=3.86+(5.09*ALOG(DIA))
     CVOL=(DP+DIA)*(535+DIA)*(339+DIA)
     CNU=ID(M)*1E15/CVOL*KS
     WRITE (8,131)M,ID(M),CNU
131  FORMAT( '   ',2I5,F12.3)
```

```
      NUD=NUD+ID(M)
  120 CONTINUE
      WRITE (8,132)NUD,MS
  132 FORMAT( '  TOTAL DROPS= ',I5,'  LARGEST DIAMETER IS ',I5,'
     2  MICROMETERS',/)
      DO 206 KK=1,MS
      J=MS-KK+1
      DIA=FLOAT(KK)
      DP=3.86+(5.09*ALOG(DIA))
      CVOL=(DP+DIA)*(535+DIA)*(339+DIA)
      CNU=ID(KK)*1E6/CVOL*KS
      RD(J)=CNU
  206 CONTINUE
      WRITE(8,1112)
      WRITE (8,105)KKS,KFM,KS
  660 WRITE(8,661) NUD,MS
  661 FORMAT( '  AVG DROPS PER 1000 CUBIC MICRONS. SIZE IN
     2 MICROMETERS ',/,' TOTAL DROPS=',I5,' LARGEST
     3 DIAMETER IS ',I5,' MICROMETERS')
      CALL USHV1(SIZE,RD,MS,IOPT,A,W,IW,IER)
  111 DO 112 NNN=1,MS
  113 DIA=FLOAT(NNN)
      DP=3.86+(5.09*ALOG(DIA))
      BHI=535.
      CVOL=(DP+DIA)*(535+DIA)*(339+DIA)
      DVOL=3.1416*NNN*NNN*NNN/6
      DOVOL=DVOL*DEN
      PPM=(1E6*DOVOL/(CVOL*KS))*ID(NNN)
      SPPM=SPPM+PPM
      RI(NNN)=PPM
  112 CONTINUE
   88 WRITE (8,105)KKS,KFM,KS
      WRITE (8,302)
  302 FORMAT( '  MG/L COMPILATION')
      WRITE (8,133)NUD,SPPM,MS
  133 FORMAT( I5,'  TOTAL DROPS',F12.1, ' TOTAL MG/L',' LARGEST DIAM
     2 =',I5,/)
      DO 135 M=1,MS
      WRITE(8,136)M,RI(M)
  136 FORMAT(I5,F12.1)
  135 CONTINUE
      DO 207 KK=1,MS
      J=MS-KK+1
      RD(J)=RI(KK)
  207 CONTINUE
      WRITE(8,1112)
 1112 FORMAT(1H1)
      WRITE (8,12)KKS,KS,KFM
      WRITE (8,145)SPPM,MS
  145 FORMAT( ' MG/L HISTOGRAM. TOTAL MG/L =',F7.0,/
```

```
     2 ,' SIZE IN MICROMETERS  LARGEST DIAM=',I5,/)
721  CALL USHV1(SIZE,RD,MS,IOPT,A,W,IW,IER)
     WRITE (8,410)SPPM,MS
410  FORMAT( '  TOTAL MG/L=',F12.1,'LARGEST DROP=',I5)
     TM=0
     ND=0
     IC=0
     DO 400 N=MS,1,-1
     TM=TM+RI(N)
     ND=ND+ID(N)
     IF(IC.GT.0)GO TO 430
     IF(TM.GT.(.25*SPPM))GO TO 405
430  IF(IC.GT.1) GO TO 431
     IF(TM.GT.(.50*SPPM))GO TO 405
431  IF(TM.GT.(.75*SPPM))GO TO 405
400  CONTINUE
     GO TO 420
405  WRITE(8,406)(TM*100/SPPM),ND,N
406  FORMAT( F12.1,'% OF THE OIL WAS IN  ',I5,
     2 ' DROPS. THE SMALLEST DIAM WAS ',I5,' U')
     IC=IC+1
     IF(IC.GT.2) GO TO 420
     GO TO 400
420  CALL CLOSE(3)
     WRITE(8,1112)
502  CONTINUE
     CALL SPOOL(8)
     END
```

SIZMIX.FTN

```
C         SIZMIX IS USED TO MIX 2 SIZE CREATED FILES.
C    IT IS USED WHEN PROCESSING IS INTERRUPTED OR
C    TO GATHER DATA FROM SEVERAL ROLLS OF FILM.
C
C    TO ENTER, SPECIFY THE TWO FILES IN THE
C    SIZEXX.DAT;YY FORM AND THE RUN NUMBER(I2)
C    OF THE DESIRED OUTPUT FILE.  THE FINAL MIXED
C    FILE IS ALSO WRITTEN INTO RAY.DMP AND SPOOLED.
C
C
     BYTE FNAME(20)
     DIMENSION I(150),I2(150),I3(150)
     TYPE 4
4    FORMAT( '$ FILE TO ACCESS IS  ')
     ACCEPT 5,N,FNAME
5    FORMAT(Q,20A1)
     IF(N.EQ.0)STOP
     CALL ASSIGN (3,FNAME,N)
```

```
      DEFINE FILE 3(1,150,U,IV)
      READ (3'1)I
      TYPE 4
      ACCEPT 5,N,FNAME
      IF(N.EQ.0)STOP
      CALL ASSIGN (4,FNAME,N)
      DEFINE FILE 4(1,150,U,IV)
      TYPE 200
200   FORMAT( '$ OUTPUT FILE NUMBER IS  ')
      ACCEPT 6,IR
6     FORMAT(I5)
      CALL FILS(FNAME,'SIZE',IR,'DAT')
      CALL ASSIGN (1,FNAME)
      DEFINE FILE 1(1,150,U,IV)
      READ (4'1)I2
      DO 100 M=1,125
      I3(M)=I(M)+I2(M)
100   CONTINUE
      I3(149)=IR
      I3(148)=IFM
      I3(147)=I(147)+I2(147)
      WRITE (1'1) I3
      CALL CLOSE(3)
      CALL CLOSE (4)
      CALL ASSIGN (2,'LS:RAY.DMP')
      WRITE (2,105)I3(149),I3(148),I3(147)
105   FORMAT( ' RUN ',I5,'  FILM ',I5,'  ',I5,' SAMPLES',//)
      DO 120 M=1,125
      WRITE (2,130) M,I3(M)
130   FORMAT(2I5)
120   CONTINUE
      CALL SPOOL (2)
      END
```

SIZMAK.FTN

```
C         SIZMAK IS DESIGNED TO CREATE A "SIZE" FILE
C     FROM A "DENS" FILE BY ELIMINATING THE
C     DENSITY DATA.  ENTER BY INPUT OF DENS FILE
C     OILXX.DAT;YY AND FOLLOW BY RUN  NUMBER
C     OF THE SIZE FILE TO MAKE.
C
C
      DOUBLE PRECISION SIZE
      DIMENSION A(600),I(150)
      BYTE FNAME(20)
      TYPE 4
4     FORMAT('$ FILE TO ACCESS IS  ')
      ACCEPT 5, N, FNAME
```

```
10    FORMAT(5012)
5     FORMAT(Q,20A1)
      IF (N.EQ.0) STOP
      CALL ASSIGN (3, FNAME,N)
      DEFINE FILE 3(1,1200,U,IV)
600   READ (3'1)A
12    FORMAT(' RUN NUMBER ', I5,I5,' WATER SAMPLES
      2 FILM ',I5,//)
      N=A(600)
      ID=A(599)
      IFM=A(598)
      TYPE 12,ID,N,IFM
      DO 320 KK=1,150
      I(KK)=0
320   CONTINUE
100   FORMAT( '$  SIZE FILE TO CREATE IS   ')
      TYPE 100
      ACCEPT 101,IR
101   FORMAT (I5)
      CALL FILS (FNAME,'SIZE',IR,'DAT')
      CALL ASSIGN (4,FNAME)
      DEFINE FILE 4(1,150,U,IV)
      CALL ASSIGN (2,'LS:OIL3.DMP')
      WRITE (2,12)IR,N,IFM
      DO 300 L=1,600,2
      IF(A(L).EQ.0.) GO TO 400
      DO 310 M=1,150
      IF(INT(A(L)+.5).EQ.M)I(M)=I(M)+1
310   CONTINUE
300   CONTINUE
400   I(149)=IR
      I(148)=IFM
      I(147)=N
      WRITE (4'1)I
      DO 330 M=1,125
      WRITE (2,340)M,I(M)
340   FORMAT(2I5)
330   CONTINUE
      CALL SPOOL (2)
      CALL CLOSE (4)
      CALL CLOSE (3)
      END
```

CAP.FTN

```
C          THIS WAS WRITTEN TO AUTO PROCESS ALL THE
C     OIL DROP DATA FILES.  ITS VALUE TO OTHERS IS THE
C     ABILITY TO CHANGE THE DATA SECTION OF IR AND D
C     TO FIT THE RUN NUMBERS AND DENSITIES IN THE NEW
```

```
C     USERS FILES.  IT IS ASSUMED THAT THIS IS DONE
C     BY A PROGRAMER AND NO INSTRUCTINS ARE NEEDED.
      BYTE FNAME(20)
      DOUBLE PRECISION SIZE
      DIMENSION A(132),RRD(150),IW(132),W(132),ID(150),IDS(150),L(11)
      DIMENSION IOPT(5),RD(125),FID(150),I(150,10),JD(10),KD(10)
      DIMENSION RI(150),RL(11),D(47),IR(47)
      DATA IOPT / 0,1,500,1,0 /
      DATA D/.834,.834,.895,.895,.895,.895,
     1 .84,.84,.84,.84,8*.84,8*.836,9*.81,
     2 4*.872,8*.86/
      DATA IR/1,2,3,4,5,6,81,91,82,92,
     1 31,32,33,34,35,37,83,93,41,42,43,
     2 44,45,47,84,94,51,52,53,54,55,56,57,
     3 85,95,61,62,63,86,71,72,73,74,76,
     4 77,87,97/
      DATA SIZE / 'SIZE    ' /
4     FORMAT('$ FILE TO ACCESS IS  ')
3     FORMAT(I5)
10    FORMAT(50I2)
5     FORMAT(Q,20A1)
501   CALL ASSIGN (8,'LS:OIL3.DMP')
      DO 502 LB=1,47
      CALL FILS(FNAME,'SIZE',IR(LB),'DAT')
      WRITE (5,550) FNAME
550   FORMAT(X,20A1)
      CALL ASSIGN (3, FNAME)
      DEFINE FILE 3(1,150,U,IV)
600   READ (3'1)ID
      SPPM=0
      NUD=0
12    FORMAT(' RUN NUMBER ', I5,I7,' WATER SAMPLES
     2 FILM ',I4)
121   FORMAT(  '  OIL DENSITY F12.5= ')
22    FORMAT(F12.5)
      DEN=D(LB)
      KKS=ID(149)
      KS=ID(147)
      KFM=ID(148)
      TYPE 12,KKS,KS,KFM
      NS=ID(147)
      WRITE (8,105)KKS,KFM,KS
105   FORMAT ( ' RUN ',I5,'  FILM ', I5,' WITH ',I5,' SAMPLES')
      WRITE(8,301)
301   FORMAT( '  DROP NUMBER COMPILATION')
      DO 151 M=1,145
      IF(ID(M).NE.0)MS=M
151   CONTINUE
      WRITE(8,25)
      DO 120 M=1,MS
```

```
25    FORMAT( ' SIZE NUMBER  DROPS PER LITER')
      DIA=FLOAT(M)
      DP=3.86+(5.09*ALOG(DIA))
      CVOL=(DP+DIA)*(535+DIA)*(339+DIA)
      CNU=ID(M)*1E15/CVOL*KS
      WRITE (8,131) M,ID(M),CNU
      NUD=NUD+ID(M)
131   FORMAT(2I5,E12.3)
120   CONTINUE
      WRITE (8,132)NUD,MS
132   FORMAT( '  TOTAL DROPS= ',I5,'  LARGEST DIAMETER IS ',I5,'
     2  MICROMETERS',/)
      DO 206 KK=1,MS
      J=MS-KK+1
      DIA=FLOAT(KK)
      DP=3.86+(5.09*ALOG(DIA))
      CVOL=(DP+DIA)*(535+DIA)*(339+DIA)
      CNU=ID(KK)*1E6/CVOL*KS
      RD(J)=CNU
206   CONTINUE
      WRITE(8,1112)
      WRITE (8,105)KKS,KFM,KS
660   WRITE(8,661) NUD,MS
661   FORMAT( ' DROPS PER THOUSAND CUBIC MICRONS-SIZE IN MICROMETERS',/
     2 ' TOTAL DROPS =',I5,'  LARGEST DIAMETER IS',I5,' MICROMETERS')
      CALL USHV1(SIZE,RD,MS,IOPT,A,W,IW,IER)
111   DO 112 NNN=1,MS
113   DIA=FLOAT(NNN)
      DP=3.86+(5.09*ALOG(DIA))
      CVOL=(DP+DIA)*(535+DIA)*(339+DIA)
      BHI=535.
      DVOL=3.1416*NNN*NNN*NNN/6
      DOVOL=DVOL*DEN
      PPM=(1E6*DOVOL/(CVOL*KS))*ID(NNN)
      SPPM=SPPM+PPM
      RI(NNN)=PPM
112   CONTINUE
88    WRITE (8,105)KKS,KFM,KS
      WRITE (8,302)
302   FORMAT( '  MG/L COMPILATION')
      WRITE (8,133)NUD,SPPM,MS
133   FORMAT( I5,'  TOTAL DROPS',F12.1, ' TOTAL MG/L',
     2 =' LARGEST DIAM= ',I5,/)
      DO 135 M=1,MS
      WRITE(8,136)M,RI(M)
136   FORMAT(I5,F12.1)
135   CONTINUE
      DO 207 KK=1,MS
      J=MS-KK+1
      RD(J)=RI(KK)
```

```
207  CONTINUE
     WRITE(8,1112)
1112 FORMAT(1H1)
     WRITE (8,12)KKS,KS,KFM
     WRITE (8,145)SPPM,MS
145  FORMAT( ' MG/L HISTOGRAM. TOTAL MG/L =',F7.0,/
     2 ,' SIZE IN MICROMETERS  LARGEST DIAM=',I5,/)
721  CALL USHV1(SIZE,RD,MS,IOPT,A,W,IW,IER)
     WRITE (8,410)SPPM,MS
410  FORMAT( '  TOTAL MG/L=',F12.1,'LARGEST DROP=',I5)
     TM=0
     ND=0
     IC=0
     DO 400 N=MS,1,-1
     TM=TM+RI(N)
     ND=ND+ID(N)
     IF(IC.GT.0)GO TO 430
     IF(TM.GT.(.25*SPPM))GO TO 405
430  IF(IC.GT.1) GO TO 431
     IF(TM.GT.(.50*SPPM))GO TO 405
431  IF(TM.GT.(.75*SPPM))GO TO 405
400  CONTINUE
     GO TO 420
405  WRITE(8,406)(TM*100/SPPM),ND,N
406  FORMAT( F12.1,'% OF THE OIL WAS IN  ',I5,
     2 ' DROPS. THE SMALLEST DIAM WAS ',I5,' U')
     IC=IC+1
     IF(IC.GT.2) GO TO 420
     GO TO 400
420  CALL CLOSE(3)
     WRITE(8,1112)
502  CONTINUE
     CALL SPOOL(8)
     END
```

ASIZNOR.FTN

```
C
C         ASIZNOR IS A PROGRAM
C    TO PROCESS A SIZE GENERATED FILE TO MAKE
C    TABLES OF THE LOG OF DIAMETER VS
C    CUMULATIVE PERCENT OF BOTH NUMBER
C    OF DROPS AND MG/L.
C
     BYTE FNAME(20)
     DOUBLE PRECISION SIZE
     DIMENSION ID(150),IOPT(5),RD(140),RI(150),D(10),IR(10)
     DIMENSION CSN(150),A(132),W(132),IW(132)
     DIMENSION CSNH(150),CDN(150),RIN(150)
```

```
      DATA IOPT / 0,1,500,1,0 /
      DATA SIZE / 'SIZE    ' /
4     FORMAT('$ FILE TO ACCESS IS  ')
      IFL=0
3     FORMAT(I5)
      DO 500 LS=1,10
      TYPE 4
      ACCEPT 3,IR(LS)
      IF (IR(LS).EQ.0)  GO TO 501
      TYPE 121
      ACCEPT 22,D(LS)
500   CONTINUE
10    FORMAT(50I2)
5     FORMAT(Q,20A1)
501   CALL ASSIGN (7,'LS:OIL3.DMP')
      LS=LS-1
      DO 502 LB=1,LS
      CALL FILS(FNAME,'SIZE',IR(LB),'DAT')
      WRITE (5,550) FNAME
550   FORMAT(X,20A1)
      CALL ASSIGN (9,FNAME)
      DEFINE FILE 9(1,150,U,IV)
600   READ (9'1)ID
      SPPM=0
      NUD=0
12    FORMAT(' RUN NUMBER ', I5,I7,' WATER SAMPLES
      2 FILM ',I4)
121   FORMAT(  '$OIL DENSITY F12.5= ')
22    FORMAT(F12.5)
      DEN=D(LB)
      KKS=ID(149)
      KS=ID(147)
      KFM=ID(148)
      TYPE 12,KKS,KS,KFM
      NS=ID(147)
      WRITE (7,105)KKS,KFM,KS
105   FORMAT ( ' RUN ',I5,'  FILM ', I5,' WITH ',I5,' SAMPLES')
      WRITE(7,301)
301   FORMAT( '  DROP NUMBER COMPILATION')
      DO 151 M=1,145
      IF(ID(M).NE.0)MS=M
151   CONTINUE
      WRITE(8,25)
25    FORMAT ( '  SIZE NUMBER  DROPS PER LITER')
      DO 120 M=1,MS
      DIA=FLOAT(M)
      DP=3.86+(5.09*ALOG(DIA))
      CVOL=(DP+DIA)*(535+DIA)*(339+DIA)
             CNU=ID(M)*1E15/CVOL*KS
             WRITE (7,131) M,ID(M),CNU
```

```
      NUD=NUD+ID(M)
  131 FORMAT( '  ',2I5,F12.3)
  120 CONTINUE
      WRITE (7,132)NUD,MS
  132 FORMAT( '  TOTAL DROPS= '  LARGEST DIAMETER IS ',I5,'
     2  ,I5,'  MICROMETERS',/)
      DO 206 KK=1,MS
      J=MS-KK+1
      RD(J)=ID(KK)/(.001*KS)
  206 CONTINUE
      WRITE(7,1112)
      WRITE (7,105)KKS,KFM,KS
      GO TO 310
  111 DO 112 NNN=1,MS
  113 DIA=FLOAT(NNN)
      DP=3.86+(5.09*ALOG(DIA))
      BHI=535.
      DVOL=3.1416*NNN*NNN*NNN/6
      CVOL=(DP+DIA)*(339+DIA)*(535+DIA)
      DOVOL=DVOL*DEN
      PPM=(1E6*DOVOL/(CVOL*KS))*ID(NNN)
      SPPM=SPPM+PPM
      RI(NNN)=PPM
  112 CONTINUE
   88 WRITE (7,105)KKS,KFM,KS
      WRITE (7,302)
  302 FORMAT( '  MG/L COMPILATION')
      WRITE (7,133)NUD,SPPM,MS
  133 FORMAT( I5,'  TOTAL DROPS',F12.1, ' TOTAL MG/L',
     2 ' LARGEST DIAM=',I5,/)
      DO 135 M=1,MS
      WRITE(7,136)M,RI(M)
  136 FORMAT(I5,F12.1)
  135 CONTINUE
      DO 207 KK=1,MS
      J=MS-KK+1
      RD(J)=RI(KK)
  207 CONTINUE
      WRITE(7,1112)
 1112 FORMAT(1H1)
  325 TM=0
      ND=0
      IC=0
      GO TO 320
  310 ISU=0
      DO 311 KK=1,MS
      ISU=ISU+ID(KK)
      CDN(KK)=(100.*ISU)/NUD
      CKK=KK
      CSN(KK)=ALOG10(CKK)
```

```
311   CONTINUE
      DO 330 KK=1,MS
      J=MS-KK+1
      CSNH(J)=CSN(KK)
      RD(J)=CDN(KK)
330   CONTINUE
      WRITE (7,105)KKS,KFM,KS
      DO 355 M=1,MS
      WRITE (7,360)CSNH(M),RD(M)
360   FORMAT(2F10.3)
355   CONTINUE
      GO TO 111
320   CSU=0
      DO 322 KK=1,MS
      CSU=CSU+RI(KK)
      RIN(KK)=CSU*100/SPPM
322   CONTINUE
      DO 340 KK=1,MS
      J=MS-KK+1
      RD(J)=RIN(KK)
340   CONTINUE
      DO 365 M=1,MS
      WRITE (7,360)CSNH(M),RD(M)
365   CONTINUE
      GO TO 420
420   CALL CLOSE(9)
502   CONTINUE
      CALL SPOOL(7)
      END
```

CAS.FTN

```
C
C          CAS AUTO=PROCESSES ALL SIZEXX.DAT FILES
C     FOR PHASE 1 AND 2 WORK.  THE RESULT IS PRODUCTION
C     OF A SERIES OF LOG-NORMAL CUMULATIVE PROBABILITY
C     PLOTS OF PERCENT DISTRIBUTION BY NUMBER VS SIZE
C     AND AN OIL3.DMP FILE THAT IS COMMENTED OUT.
C
C
      BYTE FNAME(20)
      DOUBLE PRECISION RASM
      DOUBLE PRECISION SIZE
      DIMENSION ID(150),IOPT(5),RD(140),RI(150),IR(100)
      DIMENSION IGTT(100),CSN(150),A(132),W(132),IW(132)
      DIMENSION CSNH(150),CDN(150),RIN(150),ZID(150)
      DATA IOPT / 0,1,500,1,0 /
      DATA RASM / 'RASM' /
      DATA SIZE / 'SIZE    ' /
```

```
      DATA IR/ 01,02,01,02,03,04,03,04,
      1 06,05,06,05,31,32,33,31,32,33,
      2 34,35,34,35,37,83,93,83,93,
      3 41,42,43,41,42,43,44,45,44,45,
      4 47,84,94,84,94,
      5 51,52,53,51,52,53,54,55,56,
      6 54,55,56,57,85,95,85,95,
      7 61,62,63,61,62,63,86,
      8 71,72,73,71,72,73,
      9 74,76,74,76,77,87,97,87,97,
      1 81,91,81,91,82,92,82,92,11*0/
      DATA IGTT/0,0,0,1,0,0,0,1,
      2 0,0,0,1,0,0,0,0,1,2,0,0,0,1,
      3 0,0,0,0,1,0,0,0,0,1,2,0,0,0,
      4 1,0,0,0,0,1,0,0,0,0,1,2,
      5 0,0,0,0,1,2,0,0,0,0,1,0,0,0,0,1,2,
      6 0,0,0,0,0,1,2,0,0,0,1,0,0,0,0,1,
      7 0,0,0,1,0,0,0,1,11*0/
      DATA LS/89/
      CALL PLTSET('MSGLVL',0)
4     FORMAT('$ FILE TO ACCESS IS  ')
      IFL=0
3     FORMAT(I5)
10    FORMAT(50I2)
5     FORMAT(Q,20A1)
501   CALL ASSIGN (7,'LS:OIL3.DMP')
      DO 502 LB=1,LS
      CALL FILS(FNAME,'SIZE',IR(LB),'DAT')
      WRITE (5,550) FNAME
550   FORMAT(X,20A1)
      IFL=IGTT(LB)
      NRUN = IR(LB)
      CALL ASSIGN(9,FNAME)
      DEFINE FILE 9(1,150,U,IV)
600   READ (9'1)ID
      SPPM=0
      NUD=0
12    FORMAT(' RUN NUMBER ', I5,I7,' WATER SAMPLES
      2 FILM ',I4)
121   FORMAT(  '$OIL DENSITY F12.5= ')
22    FORMAT(F12.5)
      DEN=1
      KKS=ID(149)
      KS=ID(147)
      KFM=ID(148)
      TYPE 12,KKS,KS,KFM
      NS=ID(147)
      WRITE (7,105)KKS,KFM,KS
105   FORMAT ( ' RUN ',I5,'  FILM ', I5,' WITH ',I5,' SAMPLES')
      WRITE(7,301)
```

```
301  FORMAT( '  DROP NUMBER COMPILATION')
     DO 151 M=1,145
     IF(ID(M).NE.0)MS=M
151  CONTINUE
     ZNUD=0
     DO 120 M=1,MS
     DIA=FLOAT(M)
     DP=3.86+(5.09*ALOG(DIA))
     CVOL=(DIA+DP)*(535+DIA)*(339+DIA)
     ZID(M)=ID(M)*3E6/CVOL
     ZNUD=ZNUD+ZID(M)
131  FORMAT(2I5)
120  CONTINUE
132  FORMAT( '  TOTAL DROPS= ',I5,'  LARGEST DIAMETER IS ',I5,'
     2  MICROMETERS',/)
     TYPE 132,NUD,MS
     DO 206 KK=1,MS
     J=MS-KK+1
     RD(J)=ID(KK)/(.001*KS)
206  CONTINUE
     WRITE(7,1112)
     WRITE (7,105)KKS,KFM,KS
660  WRITE(7,661) NUD,MS
661  FORMAT( '  AVG DROPS PER 1000 SAMPLES. SIZE IN MICROMETERS',/
     2 ' TOTAL DROPS =',I5,'  LARGEST DIAMETER IS',I5,' MICROMETERS')
     CALL USHV1(SIZE,RD,MS,IOPT,A,W,IW,IER)
     GO TO 310
111  DO 112 NNN=1,MS
113  DIA=FLOAT(NNN)
     DP=3.86+(5.09*ALOG(DIA))
     BHI=535.
     CVOL=DP*BHI*339
     DVOL=3.1416*NNN*NNN*NNN/6
     DOVOL=DVOL*DEN
     PPM=(1E6*DOVOL/(CVOL*KS))*ID(NNN)
     SPPM=SPPM+PPM
     RI(NNN)=PPM
112  CONTINUE
88   WRITE (7,105)KKS,KFM,KS
     WRITE (7,302)
302  FORMAT( '  MG/L COMPILATION')
     WRITE (7,133)NUD,SPPM,MS
133  FORMAT( I5,'  TOTAL DROPS',F12.1, ' TOTAL MG/L',' LARGEST DIAM
     2 =',I5,/)
     DO 135 M=1,MS
     WRITE(7,136)M,RI(M)
136  FORMAT(I5,F12.1)
135  CONTINUE
     DO 207 KK=1,MS
     J=MS-KK+1
```

```
      RD(J)=RI(KK)
207   CONTINUE
      WRITE(7,1112)
1112  FORMAT(1H1)
      WRITE (7,12)KKS,KS,KFM
      WRITE (7,145)SPPM,MS
145   FORMAT( ' MG/L HISTOGRAM. TOTAL MG/L =',F7.0,/
     2 ,' SIZE IN MICROMETERS  LARGEST DIAM=',I5,/)
721   CALL USHV1(SIZE,RD,MS,IOPT,A,W,IW,IER)
      WRITE (7,410)SPPM,MS
410   FORMAT( '  TOTAL MG/L=',F12.1,'LARGEST DROP=',I5)
325   TM=0
      ND=0
      IC=0
      DO 400 N=MS,1,-1
      TM=TM+RI(N)
      ND=ND+ID(N)
      IF(IC.GT.0)GO TO 430
      IF(TM.GT.(.25*SPPM))GO TO 405
430   IF(IC.GT.1) GO TO 431
      IF(TM.GT.(.50*SPPM))GO TO 405
431   IF(TM.GT.(.75*SPPM))GO TO 405
400   CONTINUE
      GO TO 320
310   ZISU=0
      DO 311 KK=1,MS
      ZISU=ZISU+ZID(KK)
      CDN(KK)=(100.*ZISU)/ZNUD
      CKK=KK
      CSN(KK)=ALOG10(CKK)
311   CONTINUE
      DO 330 KK=1,MS
      J=MS-KK+1
      CSNH(J)=CSN(KK)
      RD(J)=CDN(KK)
330   CONTINUE
      WRITE (7,105)KKS,KFM,KS
      DO 355 M=1,MS
      WRITE (7,360)CSNH(M),RD(M)
360   FORMAT(2F10.3)
355   CONTINUE
      IF(IGT.EQ.0)GO TO 362
362   CALL GRAPH(RD,CSNH,MS,IFL,NRUN)
      GO TO 111
320   CSU=0
      DO 322 KK=1,MS
      CSU=CSU+RI(KK)
      RIN(KK)=CSU*100/SPPM
322   CONTINUE
      DO 340 KK=1,MS
```

```
      J=MS-KK+1
      RD(J)=RIN(KK)
340   CONTINUE
      DO 365 M=1,MS
      WRITE (7,360)CSNH(M),RD(M)
365   CONTINUE
      GO TO 420
405   WRITE(7,406)(TM*100/SPPM),ND,N
406   FORMAT( F12.1,'% OF THE OIL WAS IN  ',I5,
     2 ' DROPS. THE SMALLEST DIAM WAS ',I5,' U')
      IC=IC+1
      IF(IC.GT.2) GO TO 320
      GO TO 400
420   CALL CLOSE(9)
      WRITE(7,1112)
502   CONTINUE
C     CALL SPOOL(7)
      CALL PLOT(0.,0.,999)
      CALL REQUES(RAD50(RASM))
      END


      SUBROUTINE PBGR(IFL)

      DIMENSION XP(114),P(11),DP(11),EP(11),YP(18)
      DIMENSION IXGR(10),IYGR(10),XGR(10),YGR(10)
      COMMON/XY/X(114),NX
      COMMON/SCF/XSF
      DATA IXGR / 10,25,33,48,58,68,83,91,106,0 /
      DATA IYGR / 6,8,9,10,15,18,19,0,0,0 /
      DATA XGR / .1,2.,10.,30.,50.,70.,90.,98.,99.9,0. /
      DATA YGR / 50.,30.,20.,10.,5.,2.,1.,0.,0.,0. /
      DATA P / .01,.15,.3,1.2,3.,22.,81.,98.2,99.1,99.85,99.91 /
      DATA DP / .01,.05,.1,.2,1.,2.,1.,.2,.1,.05,.01 /
      DATA EP / .1,.2,1.01,2.01,20.,80.,98.,99.,99.8,99.9,99.99 /
      NX = 1
      DO 10 I = 1,11
      CALL CX(P(I),DP(I),EP(I))
10    CONTINUE
      NXP = NX - 1
      SUM = 0.0
      DO 100 I = 2,NXP
      XP(I-1) = X(I) - X(I-1)
      SUM = SUM + XP(I-1)
100   CONTINUE
      XP(NXP) = XP(1)
      SUM = SUM + XP(NXP)
      XSF = 9.25 / SUM
      DO 110 I = 1,NXP
110   XP(I) = XP(I) * XSF
```

```
      Z = 1.
      DO 120 I = 1,9
      J = 10 - I
      YP(J) = 3.765 * (ALOG10(Z+1.) - ALOG10(Z))
      YP(J+9) = YP(J)
  120 Z = Z + 1.
      IF(IFL .NE. 0) RETURN
      R = 100.
      CALL NUMBER(.06,.29,.05,R,90.,-1)
      CALL PLOT(0.,.49,3)
      CALL PLOT(0.,9.81,2)
      CALL PLOT(7.53,9.81,2)
      CALL PLOT(7.53,.49,2)
      R = 1.
      CALL NUMBER(7.555,.29,.05,R,90.,-1)
      CALL PLOT(7.53,.56,3)
      CALL PLOT(0.,.56,2)
      XG = XP(1) + .56
      NAX = 1
      DO 130 I = 2,NXP
      CALL PLOT(0.,XG,3)
      CALL PLOT(7.53,XG,2)
      IF(IXGR(NAX) .EQ. 0) GO TO 130
      IF(IXGR(NAX) .NE. I) GO TO 130
      CALL PLOT(7.6,XG,2)
      CALL NUMBER(7.7,XG-.1,.05,XGR(NAX),90.,1)
      NAX = NAX + 1
  130 XG = XG + XP(I)
      YG = YP(1)
      NAY = 1
      DO 140 I = 2,18
      CALL NEWPEN(2)
      CALL PLOT(YG,.56,3)
      CALL PLOT(YG,9.81,2)
      IF(IYGR(NAY) .EQ. 0) GO TO 140
      IF(IYGR(NAY) .NE. I) GO TO 140
      CALL PLOT(YG,.56,3)
      CALL PLOT(YG,.49,2)
      CALL NEWPEN(1)
      CALL NUMBER(YG+.025,.29,.05,YGR(NAY),90.,-1)
      CALL NEWPEN(2)
      NAY = NAY + 1
  140 YG = YG + YP(I)
      RETURN
      END
```

```
      SUBROUTINE CX(PG,DP,EP)

      COMMON/XY/X(114),NX
      P = PG
100   PB = P / 100.
      CALL MDNRIS(PB,XPB,IER)
      X(NX) = XPB
      NX = NX + 1
      P = P + DP
      IF(P .LE. EP) GO TO 100
      RETURN
      END
```

CAM.FTN

```
C
C          CAM AUTO-PROCESSES ALL SIZEXX.DAT DATA FILES FOR
C     PHASE 1 AND 2 WORK.  THE RESULT IS PRODUCTION
C     OF  A SERIES OF LOG-NORMAL CUMULATIVE PROBABILITY PLOTS OF
C     PERCENT DISTRIBUTION BY MG/L OF OIL VS SIZE
C     AND AN OIL3.DMP FILE THAT IS COMMENTED OUT.
      BYTE FNAME(20)
      DOUBLE PRECISION RASM
      DOUBLE PRECISION SIZE
      DIMENSION ID(150),IOPT(5),RD(140),RI(150),IR(100)
      DIMENSION IGTT(100),CSN(150),A(132),W(132),IW(132)
      DIMENSION CSNH(150),D(100),CDN(150),RIN(150)
      DATA IOPT / 0,1,500,1,0 /
      DATA RASM / 'RASM' /
      DATA SIZE / 'SIZE    ' /
      DATA IR/ 01,02,01,02,03,04,03,04,
     1 06,05,06,05,31,32,33,31,32,33,
     2 34,35,34,35,37,83,93,83,93,
     3 41,42,43,41,42,43,44,45,44,45,
     4 47,84,94,84,94,
     5 51,52,53,51,52,53,54,55,56,
     6 54,55,56,57,85,95,85,95,
     7 61,62,63,61,62,63,86,
     8 71,72,73,71,72,73,
     9 74,76,74,76,77,87,97,87,97,
     1 81,91,81,91,82,92,82,92,11*0/
      DATA IGTT/0,0,0,1,0,0,0,1,
     2 0,0,0,1,0,0,0,0,0,1,2,0,0,0,1,
     3 0,0,0,0,1,0,0,0,0,0,1,2,0,0,0,
     4 1,0,0,0,0,1,0,0,0,0,0,1,2,
     5 0,0,0,0,1,2,0,0,0,0,0,1,0,0,0,0,0,1,2,
     6 0,0,0,0,0,0,1,2,0,0,0,0,1,0,0,0,0,0,1,
     7 0,0,0,1,0,0,0,1,11*0/
```

```
      DATA LS/89/
      DATA D/4*.834,8*.895,15*.84,15*.836,
     1 17*.81,7*.872,15*.86,8*.84,11*0./
      CALL PLTSET('MSGLVL',0)
      IFL=0
3     FORMAT(I5)
10    FORMAT(50I2)
5     FORMAT(Q,20A1)
501   CALL ASSIGN (7,'LS:OIL3.DMP')
      DO 502 LB=1,LS
      CALL FILS(FNAME,'SIZE',IR(LB),'DAT')
      WRITE (5,550) FNAME
550   FORMAT(X,20A1)
      IFL=IGTT(LB)
      NRUN = IR(LB)
      CALL ASSIGN(9,FNAME)
      DEFINE FILE 9(1,150,U,IV)
600   READ (9'1)ID
      SPPM=0
      NUD=0
12    FORMAT(' RUN NUMBER ', I5,I7,' WATER SAMPLES
     2 FILM ',I4)
22    FORMAT(F12.5)
      DEN=D(LB)
      KKS=ID(149)
      KS=ID(147)
      KFM=ID(148)
      NS=ID(147)
      DO 151 M=1,145
      IF(ID(M).NE.0)MS=M
151   CONTINUE
      DO 120 M=1,MS
      NUD=NUD+ID(M)
131   FORMAT(2I5)
120   CONTINUE
132   FORMAT( '  TOTAL DROPS= ',I5,'  LARGEST DIAMETER IS ',I5,'
     2  MICROMETERS',/)
      DO 206 KK=1,MS
      J=MS-KK+1
      RD(J)=ID(KK)/(.001*KS)
206   CONTINUE
661   FORMAT( '  AVG DROPS PER 1000 SAMPLES. SIZE IN MICROMETERS',/
     2 ' TOTAL DROPS =',I5,'  LARGEST DIAMETER IS',I5,' MICROMETERS')
      GO TO 310
111   DO 112 NNN=1,MS
113   DIA=FLOAT(NNN)
      DP=3.86+(5.09*ALOG(DIA))
      BHI=535.
      DVOL=3.1416*NNN*NNN*NNN/6
      CVOL=(DP+DIA)*(535+DIA)*(339+DIA)
```

```
      DOVOL=DVOL*DEN
      PPM=(1E6*DOVOL/(CVOL*KS))*ID(NNN)
      SPPM=SPPM+PPM
      RI(NNN)=PPM
  112 CONTINUE
  136 FORMAT(I5,F12.1)
  135 CONTINUE
      DO 207 KK=1,MS
      J=MS-KK+1
      RD(J)=RI(KK)
  207 CONTINUE
 1112 FORMAT(1H1)
  145 FORMAT( ' MG/L HISTOGRAM. TOTAL MG/L =',F7.0,/
     2 ,' SIZE IN MICROMETERS  LARGEST DIAM=',I5,/)
  410 FORMAT( '  TOTAL MG/L=',F12.1,'LARGEST DROP=',I5)
  325 TM=0
      ND=0
      IC=0
      GO TO 320
  310 ISU=0
      DO 311 KK=1,MS
      ISU=ISU+ID(KK)
      CDN(KK)=(100.*ISU)/NUD
      CKK=KK
      CSN(KK)=ALOG10(CKK)
  311 CONTINUE
      DO 330 KK=1,MS
      J=MS-KK+1
      CSNH(J)=CSN(KK)
      RD(J)=CDN(KK)
  330 CONTINUE
      DO 355 M=1,MS
  360 FORMAT(2F10.3)
  355 CONTINUE
      GO TO 111
  320 CSU=0
      DO 322 KK=1,MS
      CSU=CSU+RI(KK)
      RIN(KK)=CSU*100/SPPM
  322 CONTINUE
      DO 340 KK=1,MS
      J=MS-KK+1
      RD(J)=RIN(KK)
  340 CONTINUE
      DO 365 M=1,MS
  365 CONTINUE
      MMS = -MS
      CALL GRAPH(RD,CSNH,MMS,IFL,NRUN)
      GO TO 420
  406 FORMAT( F12.1,'% OF THE OIL WAS IN  ',I5,
```

```
     2 ' DROPS. THE SMALLEST DIAM WAS ',I5,' U')
     IC=IC+1
     IF(IC.GT.2) GO TO 320
420  CALL CLOSE(9)
502  CONTINUE
C    CALL SPOOL(7)
     CALL PLOT(0.,0.,999)
     CALL REQUES(RAD50(RASM))
     END


            DENS.FTN

C    DENS  A PROGRAM TO MEASURE SIZE AND POSITION
C    OF AN IMAGE IN TWO TIME LAPSE PHOTOGRAPHS,
C    CALCULATE ITS DENSITY AND DIAMETER AND STORE
C    THEM IN A FILE CALLED OILXX.DAT;YY. THE ODD
C    NUMBERED LOCATIONS HOLD THE AVERAGE DENSITY
C    OF THE TWO MEASURMENTS AND THE NEXT EVEN
C    NUMBERED LOCATION, ITS DENSITY.  A TOUCH
C    IN MENU RATHER THAN THE LOWER LEFT CORNER
C    ALLOWS THE OPTION TO TERMINATE.
C    WHEN THE TERMINAL TYPES A NUMBER IT EXPECTS A
C    TOUCH IN THE LOWER LEFT CORNER OF PHOTO #1
C    FOLLOWED BY THE X SIDES OF THE IMAGE AND
C    FOLLOWED BY THE SAME FOR PHOTO #2.
     BYTE FNAME(20),FSAME(20)
     DIMENSION  A(600)
     GO TO 500
2    FORMAT('$ I2 RUN NUMBER IS  ')
5    FORMAT(F12.6)
502  TYPE 2
     ACCEPT 3,IR
     TYPE 19
19   FORMAT  ( '$ I3 FILM NUMBER IS   ')
     ACCEPT 3, IFM
3    FORMAT(I5)
     TYPE 210
210  FORMAT ( '$ F12.6 WATER DENSITY IS   ')
     ACCEPT 5,WD
     TYPE 211
211  FORMAT( '$ F12.6 WATER VISCOSITY IS  ')
     ACCEPT 5,VIS
     AK=.098/(18*VIS)
     CALL FILS(FNAME,'OIL',IR,'DAT')
     CALL ASSIGN(2,FNAME)
     DEFINE FILE 2(1,1200,U,IV)
     A(600)=N/2
     A(599)=IR
     A(598)=IFM
```

```
      A(597)=WD
      A(596)=VIS
      WRITE(2'1)A
      CALL CLOSE(2)
      CALL FILS(FNAME,'OIL',IR,'DAT')
      CALL ASSIGN(2,FNAME)
      DEFINE FILE 2(1,1200,U,IV)
      READ (2'1)A
      DO 38, N=1,600,2
49    TYPE 3,N
56    CALL TAB(NX0,NY0,MENU)
      IF (MENU)  GO TO 29
255   CALL TAB(NX1,NY1,MENU)
      IF(MENU) GO TO 29
      CALL TAB (NX2,NY2,MENU)
      NY=IABS(NY1-NY2)
      IF(NY.GT.10)GO TO 915
      DT=(IABS(NX1-NX2))*F
      IF(DT.GT.200.OR.DT.LT.1)GO TO 250
      D1=DT
      Y1=((NY1-NY0)+(NY2-NY0))*F/2
      X1=((NX1-NX0)+(NX2-NX0))*F/2
      TYPE 76,D1,X1,Y1
76    FORMAT( '  DIAM  ',F6.1,'  X ',F6.1,'  Y ',F6.1)
48    CALL TAB(NX0,NY0,MENU)
260   CALL TAB(NX1,NY1,MENU)
      IF(MENU) GO TO 29
      CALL TAB (NX2,NY2,MENU)
      NY=IABS(NY1-NY2)
      IF(NY.GT.10)GO TO 917
      DT=(IABS(NX1-NX2))*F
      D2=DT
      Y2=((NY1-NY0)+(NY2-NY0))*F/2
      X2=((NX1-NX0)+(NX2-NX0))*F/2
      TYPE 76,D2,X2,Y2
      GO TO 35
915   TYPE 120,NY
120   FORMAT( '  DELTA Y IS ',I5)
      GO TO 255
250   TYPE 121, DT
121   FORMAT(  '  DIAM ERROR', F12.1)
      GO TO 255
917   TYPE 120,NY
      GO TO 260
43    FORMAT( ' DIAM ',F6.2,' DELTA ',F6.2, ' DENS ',F8.4,' X/DY',2F8.2)
500   TYPE 20
20    FORMAT('  CALIBRATION:ENTER MICRONS;TOUCH TWO LINES')
21    FORMAT('$ MICRONS BETWEEN LINES IS   ')
      TYPE 21
      ACCEPT 3,IM
```

```
      CALL TAB(NX1,NY1,MENU)
      CALL TAB(NX2,NY2,MENU)
      IDX=IABS(NX1-NX2)
      IDY=IABS(NY1-NY2)
      IDT=MAXO(IDX,IDY)
      FIM=FLOAT(IM)
      F=FIM/IDT
25    FORMAT('  FACTOR IS  ',F12.6)
      TYPE 25,F
      GO TO 502
35    DD=ABS(D1-D2)
      D=(D1+D2)/2.
      DY=ABS(Y1-Y2)
      X=X2-X1
30    FORMAT( '  TIME INTERVAL .3=1,1.7=2,2=3')
      TYPE 30
      ACCEPT 3,IT
      IF (IT.EQ.1) T1K=AK*.3
      IF(IT.EQ.2) T1K=AK*1.7
      IF(IT.EQ.3) T1K=AK*2
      DEN=WD-(X/(D*D*T1K))
      TYPE 43,D,DD,DEN,X,DY
      TYPE 44
44    FORMAT(  '  IF GOOD TYPE CR')
      ACCEPT 3,LK
      IF (LK.NE.0) GO TO 49
      A(N)=D
      A(N+1)=DEN
      A(600)=N/2
      A(599)=IR
      A(598)=IFM
      A(597)=WD
      A(596)=VIS
      WRITE(2'1)A
38    CONTINUE
29    TYPE 100
100   FORMAT( '  TYPE 123 TO END')
      ACCEPT 3,ITT
      IF (ITT.EQ.123)  GO TO 400
      GO TO 56
400   A(600)=N/2
      A(599)=IR
      A(598)=IFM
      A(597)=WD
      A(596)=VIS
      WRITE(2'1)A
      END
```

ALTDEN.FTN

```
C         ALTDEN IS A PROGRAM TO SEE AND /OR CHANGE
C     THE VALUE IN ANY DENS CREATED FILE.  ENTERED BY
C     GIVING THE FILE NAME; OILXX.DAT;YY.  WHEN A 0
C     LOCATION IS GIVEN, THE PROGRAM EXITS.
      DIMENSION A(600)
      BYTE FNAME(20)
21    TYPE 4
4     FORMAT('$ FILE TO ACCESS IS  ')
      ACCEPT 5, N, FNAME
10    FORMAT(5012)
5     FORMAT(Q,20A1)
      IF (N.EQ.0) STOP
      CALL ASSIGN (3, FNAME,N)
      DEFINE FILE 3(1,1200,U,IV)
      READ(3'1)A
      TYPE 200,A(599),A(598),A(600)
100   TYPE 103
200   FORMAT( '  RUN ',F10.5,' FILM',F10.5,' SAMPLES',F10.5)
102   FORMAT(Q,F10.5)
103   FORMAT( '$ NUMBER TO CHANGE IS   ')
      ACCEPT 112,NN
112   FORMAT(I5)
      IF(NN.EQ.0) GO TO 20
      READ (3'1)A
      TYPE 104,A(NN)
104   FORMAT( ' IS ',F10.5,' CHANGE TO ? CR=NO CHANGE')
      ACCEPT 102,NQ,ADT
      IF(NQ.EQ.0) GO TO 100
      A(NN)=ADT
      WRITE (3'1)A
      GO TO 100
20    CALL CLOSE (3)
      END
```

DENSPR.FTN

```
C       DENSPR  THE PROGRAM PROCESSES AND SPOOLS THE
C     DATA IN A DENS CREATED FILE.  IT IS ENTERED BY
C     INPUT OF THE FILE NAME: OILXX.DAT;YY.  PROCESSING
C     IS AUTOMATIC RESULTING IN A COMPILATION OF INTEGER
C     DROP DIAMETER IN MICROMETERS AND DENSITIES OF ALL
C     DROPS OF THAT DIAMETER.
      DOUBLE PRECISION SIZE
      DIMENSION A(600), D(125,50)
      BYTE FNAME(20)
      DATA D/6250*0./
      DATA SIZE / 'SIZE    ' /
      TYPE 4
```

```
4     FORMAT('$ FILE TO ACCESS IS  ')
      ACCEPT 5, N, FNAME
10    FORMAT(50I2)
5     FORMAT(Q,20A1)
      IF (N.EQ.0) STOP
      CALL ASSIGN (3, FNAME,N)
      DEFINE FILE 3(1,1200,U,IV)
600   READ (3'1)A
      CALL ASSIGN (2,'LS:OIL.DMP')
      DO 100 N=1,125
      J=0
      DO 101 M=1,600,2
      IF(A(M).EQ.0) GO TO 109
      K=INT(A(M)+.5)
      IF(K.EQ.N) GO TO 110
101   CONTINUE
109   D(N,50)=J
100   CONTINUE
      GO TO 111
110   J=J+1
      D(N,J)=A(M+1)
      GO TO 101
111   WRITE(2,120)A(599)
120   FORMAT( '  RUN NUMBER',F5.0)
      DO 112 N=1,125
      IF(D(N,1).EQ.0) GO TO 112
      ID=D(N,50)
      WRITE(2,115)N,ID
117   FORMAT(10F7.4)
115   FORMAT(  '  DIAM=', I3,'  TOTAL DROPS=' ,I3)
      WRITE(2,117)(D(N,I),I=1,ID)
112   CONTINUE
      CALL SPOOL (2)
      END


      SUBROUTINE GRAPH(X,Y,MS,IFL,NRUN)

      DIMENSION X(1),Y(1),XP(152),YP(152)
      COMMON/SCF/XSF
      DATA X1 / -3.71898 /
      DATA YOFF / 7.53 /
      IF(IFL .EQ. 0) CALL PLOT(0.,0.,-999)
      CALL NEWPEN(1)
      CALL PBGR(IFL)
      IF(IFL .NE. 0) GO TO 20
      IF(MS .LT. 0) GO TO 10
      CALL SYMBOL(7.9,.56,.12,
     1'CUMULATIVE % BY NUMBER OF DROPS WITH SMALLER DIAMETERS',
     290.,54)
```

```
      GO TO 20
   10 CALL SYMBOL(7.9,.56,.12,
     1'CUMULATIVE % BY MG/L OIL IN DROPS WITH SMALLER DIAMETERS',
     290.,56)
   20 MS = IABS(MS)
      IF(IFL .NE. 0) GO TO 30
      CALL SYMBOL(7.9,8.37,.12,'RUN',90.,3)
   30 XG = FLOAT(IFL) * .36
      R = NRUN
      CALL NUMBER(7.9,8.9+XG,.12,R,90.,-1)
      DO 100 I = 1,MS
      XX = X(I)
      IF(XX .GT. 99.99) XX = 99.99
      IF(XX .LT. .01) XX = .01
      XX = XX / 100.
      CALL MDNRIS(XX,XP(I),IER)
      XP(I) = ((XP(I) - X1) * XSF) + .56
      YP(I) = Y(I)
      IF(YP(I) .GT. 2.) YP(I) = 2.
      YP(I) = YOFF - (YP(I) * 3.765)
  100 CONTINUE
      CALL NEWPEN(5)
      CALL PLOT(YP(1),XP(1),3)
      DO 200 I = 2,MS
      CALL PLOT(YP(I),XP(I),2)
  200 CONTINUE
      RETURN
      END
      SUBROUTINE GRAPH(X,Y,MS,IFL,NRUN)
      DIMENSION X(1),Y(1),XP(152),YP(152)
      COMMON/SCF/XSF
      DATA X1 / -3.71898 /
      DATA YOFF / 7.53 /
      IF(IFL .EQ. 0) CALL PLOT(0.,0.,-999)
      CALL NEWPEN(1)
      CALL PBGR(IFL)
      IF(IFL .NE. 0) GO TO 20
      IF(MS .LT. 0) GO TO 10
      CALL SYMBOL(7.9,.56,.12,
      1'CUMULATIVE % BY NUMBER OF DROPS WITH SMALLER DIAMETERS',
      290.,54)
      GO TO 20
   10 CALL SYMBOL(7.9,.56,.12,
      1'CUMULATIVE % BY MG/L OIL IN DROPS WITH SMALLER DIAMETERS',
      290.,56)
   20 MS = IABS(MS)
      IF(IFL .NE. 0) GO TO 30
      CALL SYMBOL(7.9,8.37,.12,'RUN',90.,3)
   30 XG = FLOAT(IFL) * .36
      R = NRUN
```

```
      CALL NUMBER(7.9,8.9+XG,.12,R,90.,-1)
      DO 100 I = 1,MS
      XX = X(I)
      IF(XX .GT. 99.99) XX = 99.99
      IF(XX .LT. .01) XX = .01
      XX = XX / 100.
      CALL MDNRIS(XX,XP(I),IER)
      XP(I) = ((XP(I) - X1) * XSF) + .56
      YP(I) = Y(I)
      IF(YP(I) .GT. 2.) YP(I) = 2.
      YP(I) = YOFF - (YP(I) * 3.765)
100   CONTINUE
      CALL NEWPEN(5)
      CALL PLOT(YP(1),XP(1),3)
      DO 200 I = 2,MS
      CALL PLOT(YP(I),XP(I),2)
200   CONTINUE
      RETURN
      END
```

APPENDIX C

WALL-CENTER SAMPLES

One of the platforms studied presented a unique opportunity to study the effect of sample withdrawal from the pipeline wall and center. Both the inlet and outlet of the Wemco final heater treating unit were equipped with large gate valves that would allow passage of a 1/2-in-diameter tube. A Swagelok 1/2-in connector was altered to allow passage of the 1/2-in tube through the fitting. This is accomplished by passing a 17/32-in drill through the fitting to remove the tube travel limiting shoulder in the fitting. A sample withdrawal tube was prepared from 12.7 mm OD x .7 mm wall (1/2-in x .028 in) stainless tubing by silver soldering a thin plug into one end and drilling a 9.5-mm hole in the sidewall at the plugged end. The sample transmission line was connected to the open end of the 12.7-mm tube. the 12.7-mm tube was long enough to extend well past the center of the pipeline.

To use the sample apparatus, the modified Swagelok connector was screwed into the open end of the closed gate valve. Teflon front and rear Swagelok ferrules were placed in the tube connection end and the 12.7-mm tube inserted. The tube was inserted to the face of the closed gate and the fitting tightened just enough to prevent water leakage when the gate valve was opened. The gate valve was then opened and the tube inserted further, sliding through the incompletely tightened fitting, until the sidewall hole was at the center of the pipeline. The tube was rotated until the hole was "looking upstream." The system was then established to take pipeline center samples. A similar technique was used to position the sample hole in the 12.7-mm probe at the wall for taking a wall sample. All distances were established by measurement of the tube extending from the fitting.

The data in Table C-1 were taken by exposing rolls of film with the sample probe placed alternately at the wall and at the center to minimize the effect of changing platform conditions. Two statisticians have inspected the data and rendered exactly opposite decisions as to the effect of sample point on drop size dispersion. Both, however, said that there was no large and obvious difference. The conclusion of the authors is that any effect on drop size dispersion by the sample point is small and may be masked by the moment-to-moment change in the sample stream. Other experiments could certainly be designed to study the problem in detail, but this was beyond the scope of the reported investigation. Based on the intuitive feeling that center samples would be more representative of the stream, the sample probe was used when possible.

TABLE C-1. ST177 DATA, WALL AND CENTER SAMPLES
(total drop count in each size range)

Size	Wemco Inlet Center		Wemco Inlet Wall		Wemco Outlet Center			Wemco Outlet Wall		
Run Order:	1	3	2	4	1	3	5	2	4	6
1	3	1	5	1	11	17	7	15	18	16
2	24	48	59	59	82	109	129	77	151	103
3	180	193	314	185	137	99	79	75	29	57
4	191	137	177	90	62	22	12	19	12	17
5	104	69	79	53	23	9	7	8	9	5
6	46	48	52	22	19	1	5	4	5	4
7	32	30	35	19	6	5		1	3	
8	22	11	24	20	6			1	2	
9	20	18	14	10	2	1		1		2
10	6	6	6	4	4	2			1	
11	4	4	8	2	1					
12	5	4	2	1				2	1	
13	4	4	2	3	2	1		2		
14	3	3	5	5				1	1	
15	1		1	1	1					
16	2	4	2		1					
17	2	6	1	1						
18		1	1				1			
19	2	4	3	1						
20	1	1		1						
21		3	2	1	2					
22		1		3						
23				1						
24	1									
25	1	3								
26	1	1	1							
27	1	1	1							
28	1									
29		1								
30			1		1					
31			1							
32		1			1					
33										
34	1	1								
35										
36										
37										
38		1								
39										
40			2							
41			1							
42								1		
43			1							
44										
45										
46										
47										
48										
49										
50										
51										
52										
53										
54										
55		1								
56										
57										